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National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Division

1989

PREFACE

This publication is a compilation of summaries of reports written by Principal Investigators funded through the Planetary Astronomy Program of NASA's Solar System Exploration Division, Office of Space Science and Applications.

The summaries are designed to provide information about current scientific research projects conducted in the Planetary Astronomy Program and to facilitate communications and coordination among concerned scientists and interested persons in universities, government, and industry.

The reports are published as they were submitted by the Principal Investigators and have not been edited. They are arranged in alphabetical order.

In a second section, highlights of recent accomplishments in Planetary Astronomy are summarized as they were submitted by the principal investigators. The name attached to an individual paragraph is generally the name of the person who submitted that paragraph.

Jürgen Rahe
Discipline Scientist
Planetary Astronomy Program
Solar System Exploration Division

June 1989

LIST OF PRINCIPAL INVESTIGATORS

A'Hearn, M.F.	UMD	Observations of Comets and Asteroids
A'Hearn, M.F.	UMD	Theoretical Spectroscopy of Comets
Baum, W.A.	LOWELL	Planetary Research at Lowell Observatory
Beebe, R.	NMSU	Long-Term Changes in Reflectivity and Large Scale Motions in the Atmospheres of Jupiter and Saturn
Bell, J.F.	UHI	Infrared Spectral Studies of Asteroids
Bell, J.F.	UHI	Reflectance Spectroscopy of Phobos and Deimos
Belton, M.J.S.	KPNO	Photometric and Astrometric Reductions of P/Halley CCD Data
Binzel, R.P.	MIT	Photometry of Pluto-Charon Mutual Events and Hirayama Family Asteroids
Bowell, E.	LOWELL	Studies of Asteroids, Comets, and Jupiter's Outer Satellites
Brandt, J.C.	UCO	Evolution of Large-Scale Plasma Structures in Comets: Kinematics and Physics
Brown, R.H.	JPL	Infrared Observations of Small Solar-System Bodies
Campbell, D.B.	NAIC	Arecibo S-Band Radar Program
Chapman, C.R.	PSI	Planetary Astronomy
Crisp, D.	JPL	Near-Infrared Observations of the Venus Night Side
Deming, D.	GSFC	Spectroscopic Planetary Detection
Elliot, J.L.	MIT	Occultation Studies of the Solar System
Fink, U.	UAZ	Planetary Spectroscopy

French, L.M.	LOWELL	CCD Photometry of Trojan Asteroids
Gehrels, T.	UAZ	CCD Scanning for Comets and Asteroids
Goldberg, B.A.	JPL	High-Resolution Imaging of Solar System Objects
Gulkis, S.	JPL	Submillimeter Heterodyne Receiver for the CSO Telescope
Hall, D.N.B.	UHI	Research in Planetary Studies and Operation of Mauna Kea Observatory
Hanner, M.S.	JPL	Infrared Observations of Periodic Comets
Harris, A.W.	JPL	Table Mountain Observatory Support to Other Programs
Helin, E.F.	JPL	Palomar Planet-Crossing Asteroid Survey (PCAS)
Holberg, J.B.	UAZ	Extreme and Far Ultraviolet Astronomical Observations with the Voyager Ultraviolet Spectrometers
Howell, R.R.	UWY	Infrared Speckle Interferometry and Spectroscopy of Io
Hunten, D.M.	UAZ	Studies of Extended Planetary Atmospheres
Irvine, W.M.	UMA	Radiative Transfer in Planetary Atmospheres
Jennings, D.E.	GSFC	High Resolution Infrared Planetary Astronomy Using Cryogenic Grating Spectrometers
Jewitt, D.	UHI	Temporal Monitoring of Active Comets
Johnson, T.V.	JPL	Infrared Observations of Outer Planet Satellites
Jurgens, R.F.	JPL	Goldstone Solar System Radar

Klein, M.J.	JPL	Planetary Microwave and Submillimeter Astronomy
Klemola, A.R.	UCA	Solar System Occultation Surveys
Knacke, R.	SUNY	Infrared Spectroscopy of Jupiter and Saturn
Kostiuk, T.	GSFC	Advanced Infrared Astronomy
Larson, S.M.	UAZ	Cometary Spectroscopy and Imaging
Lebofsky, L.A.	UAZ	Infrared Observations of Solar System Objects
Lutz, B.L.	LOWELL	Outer Planet Studies
Lutz, B.L.	LOWELL	Photopolarimetric Imaging of the Giant Planets
Matson, D.L.	JPL	Asteroid Research
McCrosky, R.E.	SAO	Investigation of Prairie Network Geminid Fireballs
McCrosky, R.E.	SAO	Astrometric Observations of Comets and Asteroids and Subsequent Orbital Investigations
McMillan, R.S.	UAZ	The Radial Velocity Search for Extra Solar Planets
Millis, R.L.	LOWELL	Occultation Studies of the Solar System
Mink, D.J.	SAO	A Search for Stellar Occultations by Uranus, Neptune, Pluto, and Their Satellites: 1990-1999
Muhleman, D.O.	CIT	Synthetic Aperture Planetary Radar Astronomy Using the Very Large Array
Muhleman, D.O.	CIT	Lunar and Planetary Studies
Muhleman, D.O.	CIT	Submillimeter and Millimeter Observations of Solar System Objects
Newburn, R.L., Jr.	JPL	Physical Processes in Comets

Orton, G.S.	JPL	Infrared Astronomy of Planetary Atmospheres
Ostro, S.J.	JPL	Radar Investigation of Asteroids and Planetary Satellites
Owen, T.	SUNY	Spectroscopic Observations of the Planets
Potter, A.E.	JSC	Observational Studies of the Exospheres of Mercury and the Moon
Scherb, F.	UWI	Fabry-Perot Ground-Based Observations of Comets and the Jupiter Plasma Torus
Smith, B.A.	UAZ	Studies in Planetary Sciences
Snyder, L.E.	UIL	Radio Astronomical Studies of Comets with the Very Large Array
Soifer, B.T.	CIT	Planetary Astronomy
Spinrad, H.	UCA	Spatially Resolved Quantitative Spectroscopy and Imaging of Comets
Tedesco, E.F.	JPL	Asteroid Shapes and Pole Orientations from Visual and Infrared Photometry
Terrile, R.J.	JPL	Planetary Optical and Infrared Imaging
Veeder, G.J.	JPL	Physical Properties of Asteroids
Webster, W.J., Jr.	GSFC	Passive Microwave Remote Sensing of the Asteroids Using the VLA
Williams, J.G.	JPL	Astrometric Observations of Asteroids and Small Bodies
Wyckoff, S.	ASU	Spectroscopy of Comets
Yeomans, D.K.	JPL	Comet and Asteroid Dynamics

HIGHLIGHTS OF RECENT ACCOMPLISHMENTS

A "TWIN" OF COMET P/HALLEY	M.F. A'HEARN
THE WATER CONTENT OF DEIMOS	J.F. BELL
OBSERVATIONS OF PLUTO-CHARON MUTUAL EVENTS	R.P. BINZEL
RADAR IMAGERY OF VENUS	D.B. CAMPBELL
PLUTO'S ATMOSPHERE	J.L. ELLIOT
CCD PHOTOMETRY OF TROJAN ASTEROIDS	L.M. FRENCH
CCD SCANNING FOR COMETS AND ASTEROIDS	T. GEHRELS
SILICATE EMISSION IN COMET BRADFIELD (1987s)	S. HANNER
THE PALOMAR PLANET-CROSSING ASTEROID SURVEY (PCAS)	E.F. HELIN
INFRARED SPECKLE INTERFEROMETRY AND SPECTROSCOPY OF IO	R.R. HOWELL
A LUNAR SODIUM ATMOSPHERE	D.M. HUNTEN
THE REFLECTION OF LIGHT FROM ROUGH PLANETARY AND SATELLITE SURFACES	W.M. IRVINE
STUDY OF MICROWAVE EMISSION BY THE OH RADICAL IN RECENT COMETS	W.M. IRVINE
DEUTERATED WATER ON MARS	D.E. JENNINGS
CONTINUOUS ACTIVITY IN COMET P/SCHWASSMANN WACHMANN 1	D.C. JEWITT
SYNCHROTRON EMISSION FROM JUPITER SHOWS CORRELATION WITH SOLAR WIND	M.J. KLEIN
ADVANCED INFRARED ASTRONOMY	T. KOSTIUK
HIGH RESOLUTION GROUNDBASED IMAGES OF MARS	S. LARSON
3 um SPECTROSCOPY OF ASTEROIDS	L.A. LEBOWSKY
ASTROMETRIC OBSERVATIONS OF COMETS AND ASTEROIDS AND SUBSEQUENT ORBITAL INVESTIGATIONS	R.E. MCCROSKY
HAZY ATMOSPHERE REVEALED ON PLUTO	R.L. MILLIS
AN ADVANCE IN KNOWLEDGE OF COMETS	R.L. NEWBURN, JR.

INFRARED ASTRONOMY OF PLANETARY ATMOSPHERES.	G. ORTON
RADAR OBSERVATIONS OF ASTEROID 1986 JK	S.J. OSTRO
RADAR DETECTION OF PHOBOS	S.J. OSTRO
DISCOVERY OF SODIUM AND POTASSIUM VAPOR IN THE LUNAR ATMOSPHERE	A.E. POTTER
FABRY-PEROT GROUND-BASED OBSERVATIONS OF COMETS	F. SCHERB
FABRY-PEROT GROUND-BASED OBSERVATIONS OF THE JUPITER PLASMA TORUS	F. SCHERB
DETECTION OF FORMALDEHYDE EMISSION FROM COMET HALLEY	L.E. SNYDER
THE REMARKABLE RADIO OH EMISSION FROM COMET WILSON (19861)	L.E. SNYDER
RESEARCH IN PLANETARY ASTRONOMY AT PALOMAR OBSERVATORY	B.T. SOIFER
THE ASTEROIDS II MACHINE-READABLE DATA BASE	E.F. TEDESCO
TESTS OF IMPROVED CORONAGRAPHIC INSTRUMENTS ON GROUND-BASED TELESCOPES	R.J. TERRILE
PASSIVE MICROWAVE OBSERVATIONS OF ASTEROIDS . .	W.J. WEBSTER, JR.
ASTROMETRIC OBSERVATIONS OF ASTEROIDS AND SMALL BODIES	J.G. WILLIAMS
SPECTROSCOPY OF COMETS	S. WYCKOFF
COMET AND ASTEROID DYNAMICS	D.K. YEOMANS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Observations of Comets and Asteroids

PERFORMING ORGANIZATION

Astronomy Program
University of Maryland
College Park, MD 20742

INVESTIGATOR'S NAME

Michael F. A'Hearn

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy We use all available ground-based observational techniques to study the chemical and physical properties of the small bodies of the solar system, primarily comets and secondarily asteroids. The ultimate goal is to use these bodies to understand the formation and evolution of the solar system.

b. Accomplishments 1988-89 (i) Virtually all (>600) ccd images of Halley have been archived with IHW Near-Nucleus Studies Net. (ii) Completed an analysis of dust images and showed quantitatively that "red jets" and "red envelope" can both be explained in terms of size-sorting of particles by radiation pressure without invoking chemical inhomogeneities. (iii) Carried out photometry of images of P/Halley from first half of 1987 and showed that any variability is small and we could therefore not reach conclusions about the rotation period. (iv) Observed comet P/Tempel 2 in optical and infrared and derived numerous properties of the nucleus including size, shape and albedo (a twin of Halley in these characteristics) color and active surface fraction (of order 1%). (v) Analyzed numerous sets of ground-based data to test whether NH_2 and NH can be explained as products of NH_3 . They can be and we confirm the low abundance of NH_3 ($\sim 1/2$ %) in P/Halley suggested by some, contrary to Giotto results.

c. Plan for Next Year (i) Analysis of ccd images of P/Halley to relate dust jets with gas jets. (ii) Quantitative model of gas jets. (iii) CCD and spectroscopic observations of Brorsen-Metcalf. (iv) Complete upgrade of ccd system. (v) completion of re-analysis of photometric survey.

d. Publications 1988-89

Observations of Comets and Asteroids - NSG 7322

Hoban, S., A'Hearn, M.F., Birch, P.V., and Martin, R. 1989, "Spatial Structure in the Color of the Dust Coma of Comet P/Halley," *Icarus*, in press.

Weissman, P.R., A'Hearn, M.F., McFadden, L.A., and Richman, H. 1989, "Evolution of Comets into Asteroids," in *Asteroids*, ed. Binzel and Matthews, U. Arizona Press. in press.

A'Hearn, M.F., Campins, H., Schleicher, D.G., Millis, R.L. 1989 "The Nucleus of Comet P/Tempel 2," manuscript prepared for submission to *Astrophys. J.*

Hoban, S. 1989 Comet Halley: An Optical Continuum Study, Ph.D. Thesis, University of Maryland, to be submitted March 1989.

In addition, there were two papers presented at the DPS meeting in November 1988 (papers 08.06 and 11.03) and one at the AAS meeting in January 1989. Published only as abstracts.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Theoretical Spectroscopy of Comets

PERFORMING ORGANIZATION

Astronomy Program
University of Maryland
College Park, MD 20742

INVESTIGATOR'S NAME

Michael F. A'Hearn

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy We calculate theoretical spectra of various emitting species in cometary comae both to investigate physical parameters that are measurable with cometary spectra and to provide fluorescence efficiencies for the derivation of abundances from fluxes.

b. Accomplishments 1988-89 (i) Analyzed ground-based spectra of comet I-A-A obtained by S. Larson. Showed that S_2 undergoes numerous outbursts in this comet and that the optical bands are much stronger than the ultraviolet bands but equally confined to a very small spatial region. This tends to confirm the ubiquity of S_2 in comets. (ii) Completed quantitative analysis of upper limits on abundance of SO in comets. Upper limit for I-A-A is about 10 x abundance of S_2 - comparable to what is predicted by irradiation experiments. Upper limits for other comets are higher. More sensitivity is needed to search for SO in other comets requiring HST rather than IUE. (iii) Showed that anomalies in the observed spectrum of CS can probably be explained by tracking errors of IUE rather than by unusual physical conditions as apparently required in other analyses. (iv) Initiated analysis of SO_2 to predict spectrum since SO_2 should be produced together with SO in comets. (v) Collaborated with D. Schleicher on analysis of quenching of OH Λ -doublet by collisions.

c. Plan for Next Year (i) Publish the numerous half-finished manuscripts. (ii) Complete model for spectrum of SO_2 and compare with extant data. (iii) Extend calculations to other carbon compounds, particularly ions - CO, CO_2^+ , CS^+ .

d. Publications 1988-89

Theoretical Spectroscopy of Comets - NAGW 902

A'Hearn, M.F. 1988 "Comets" in A Decade of UV Astronomy with IUE, ESA SP-281, pp. 47-58.

A'Hearn, M.F. and Schleicher, D.G. 1988 "Comet P/Encke's Nongravitational Force," Astrophys.J. (Letters) 331, L47-L51.

Kim, S.J., A'Hearn, M.F. and Cochran, W.D. 1989 "NH Emissions in Comets: Fluorescence vs. Collisions," Icarus 77, 98-108.

Schleicher, D.G. and A'Hearn, M.F. 1988 "The Fluorescence of Cometary OH," Astrophys. J. 331, 1058-1077.

Kim, S.J. and A'Hearn, M.F. 1989 "Sulfur Compounds in Comets," paper for CNRS meeting.

In addition, two papers were presented at the November 1988 DPS meeting (papers 08.02 and 08.03) but published only as abstracts. Three manuscripts are in hand but not yet ready for submission.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Research at Lowell Observatory
NGR-03-003-001

PERFORMING ORGANIZATION

Lowell Observatory
Mars Hill Road
Flagstaff, Arizona 86001

INVESTIGATOR'S NAME

William A. Baum
602-774-3358

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

(a) Research under this grant currently deals largely with comets. Present scientific goals include a better determination of the basic physical characteristics of cometary nuclei, a more complete understanding of the complex processes in the comae, and a survey of abundances and gas/dust ratios in a large number of comets. Recent previous work has included primordial $^{12}\text{C}/^{13}\text{C}$ and $^{14}\text{N}/^{15}\text{N}$ ratios in comets, observations of Pluto-Charon mutual eclipses to help derive dimensions, and analysis of the risk of Cassini colliding with Saturn E-ring particles.

(b) A paper on revised scale lengths for cometary NH is now in press and will appear in a forthcoming issue of the *Astrophysical Journal*. It was found that a parent scale length 5 to 10 times previously published values is required to fit narrowband aperture photometry of Comets P/Halley, P/Borrelly, and Liller. In June 1988, simultaneous optical and thermal infrared observations were obtained of Comet P/Tempel 2 (in collaboration with M.F. A'Hearn and H. Campins) using the MKO 2.2-meter telescope and the NASA IRTF. Analysis of these observations, now in preparation for publication, shows that the comet's nucleus is highly elongated, very dark, and quite red. Coronagraphic CCD images of Saturn's E-ring, obtained when the rings were last edge-on and published in two earlier papers, were re-analyzed with respect to the risk of particle impacts on the Cassini spacecraft and were reported at two meetings. Continuum luminosity profiles, indicative of grain sublimation, were derived from CCD images of Comets P/Borrelly, Furuyama, and Bradfield. In June, similar CCD imaging observations were obtained of Comets Liller and P/Tempel 2. Pluto-Charon mutual events were observed in March and May 1988.

(c) Existing photometry of 75 comets observed by us since 1976 will be reduced to a common photometric system, and the results will be discussed in terms of group properties of comets. Luminosity profile data from CCD images of 17 comets in continuum passbands will be interpreted in terms of grain properties. This year's wide-field CCD observations of Comet P/Brorsen-Metcalf, if successful, will be added to that data set. Observations of Comets P/Schwassmann-Wachmann 3 and P/Honda-Mrkos-Pajdusakova are planned in 1990 in order to measure fundamental properties of their nuclei, to search for periodic variability, and to test our recent findings about NH. Observations of P/Kopff will also be attempted. Pluto-Charon photometry will be completed.

(d) Bibliography of papers since January 1987:

- Baum W. A., Kreidl, T. J., and Schleicher, D. G. (1987). Assaying cometary grains. *Bull. Amer. Astron. Soc.* **19**, 868.
- Baum, W. A., and Kreidl, T. J. (1988). What Cassini will fly through. *Bull. Amer. Astron. Soc.* **20**, 850-851.
- Baum, W. A., and Kreidl, T. J. (1989). Comet-to-comet differences in coma grain properties. To be presented at *Asteroids, Comets, Meteors III* in Uppsala.
- Baum, W. A., Kreidl, T. J., and Schleicher, D. G. (1989). Cometary grains. *Astron. J.*, in preparation.
- Millis, R. L., Schleicher, D. G., Birch, P. V., Martin, R., and A'Hearn, M. F. (1987). Production of gas and dust by Comet Halley. *Bull. Amer. Astron. Soc.* **19**, 880.
- Millis, R. L., A'Hearn, M., and Campins, H. (1988). An investigation of the nucleus and coma of Comet P/Arend-Rigaux. *Astrophys. J.* **324**, 1194-1209.
- Millis, R. L., Schleicher, and Birch, P. V. (1988). Narrowband filter photometry of Comet P/Halley in 1985/1986. In preparation.
- Millis, R. L., A'Hearn, M. F., Schleicher, D. G., and Birch, P. V. (1989). Twelve years of comet photometry. To be presented at the *Comets in the Post-Halley Era* meeting in Bamberg.
- Millis, R. L., Schleicher, D. G., Thompson, D. T., Bus, S., Birch, P. V., Martin, R., and A'Hearn, M. F. (1989). Narrowband filter photometry of Comet P/Halley in 1985/1986. In preparation.
- Millis, R. L. (with W. Osborn, M. F. A'Hearn, U. Carsenty, D. G. Schleicher, P. V. Birch, H. Moreno, A. Gutierrez, and E. Wenderoth). (1989). Standard stars for comet photometry. In preparation.
- Schleicher, D. G., Millis, R. L., and Birch, P. V. (1987). Photometric observations of Comet P/Giacobini-Zinner. *Astron. Astrophys.* **187**, 531-538.
- Schleicher, D. G., Millis, R. L., Tholen, D. J., Hammel, H. B., Piscitelli, J. R., Lark, N., Birch, P. V., and Martin, R. (1987). The variability of Comet Halley during the 1985/1986 apparition. *Bull. Amer. Astron. Soc.* **19**, 879.
- Schleicher, D. G., and Millis, R. L. (1988). Revised scalelengths for cometary NH. *Bull. Amer. Astron. Soc.* **20**, 821.
- Schleicher, D. G., and Millis, R. L. (1988). Revised scale lengths for cometary NH. *Astrophys. J.*, in press.
- Schleicher, D. (with M. A'Hearn and H. Campins). (1988). The nucleus of Comet P/Tempel 2. *IAU Circulars*, No. 4614.
- Schleicher, D. (with M. A'Hearn, P. Feldman, and E. Roettger). (1988). Production rates of Comet P/Tempel 2. *IAU Circulars*, No. 4622.
- Schleicher, D. G. (with H. Campins, M. F. A'Hearn, and R. L. Millis). (1988). The nucleus of Comet P/Tempel 2. *Bull. Amer. Astron. Soc.* **20**, 835.
- Schleicher, D. G., Millis, R. L., Thompson, D. T., Tholen, D. J., Hammel, H. B., Piscitelli, J. R., Lark, N., Birch, P. V., and Martin, R. (1989). The variability of Comet Halley during the 1985/1986 apparition. In preparation.
- Schleicher, D. G., Millis, R. L., Thompson, D. T., Tholen, D. J., Hammel, H. B., Piscitelli, J. R., Lark, N., Birch, P. V., and Martin, R. (1989). The variability of Comet P/Halley during the 1985/1986 apparition. To be presented at the *Comets in the Post-Halley Era* meeting in Bamberg.
- Schleicher, D. G. (with M. F. A'Hearn, H. Campins, and R. L. Millis). (1989). The nucleus of Comet P/Tempel 2. In preparation.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Long-Term Changes in Reflectivity and Large Scale Motions in the Atmospheres of Jupiter and Saturn

PERFORMING ORGANIZATION

Department of Astronomy, New Mexico State University

INVESTIGATOR'S NAME

Reta Beebe, Department of Astronomy, New Mexico State Univ.,
Box 30001/ Dept. 4500, Las Cruces, New Mexico, 88003-0001.

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year; d. Summary bibliography)

a) Strategy

This research involves continuous multicolor imaging of the cloud-decks of Jupiter and Saturn. A dedicated 60 cm. telescope, coupled with a CCD camera that is driven with an IBM-AT clone, yields high quality monitored images through interference filters with central wavelengths ranging from 440 to 968 nm. The band-passes of the filters have been chosen to satisfy three criteria: a) blue and orange broad-band filters for short exposures with maximum spatial resolution for monitoring changes in cloud morphology, b) a set of interference filters centered at wavelengths with strong and weak methane absorption to allow vertical discrimination and c) the set of filters selected by the Galileo imaging team. The goal of this research is to characterize the long-term changes in the cloud deck and to provide a continuous link of the Galileo observations with the Pioneer and Voyager data sets.

b) Progress and Accomplishments of Prior Year

Programming of the CCD camera and for data archiving has been achieved and the multicolor monitoring of Jupiter is nearing completion. Flat-fields and regular monitoring of standard stars have been included in the sequence and work has begun to reduce the images to absolute surface brightness. Selected images have been processed to remove limb darkening and have been map projected for cross-correlation to derive cloud displacements and wind fields.

c) Accomplishments This Year

The images of Jupiter will be reduced to absolute surface brightness and archived for comparison with previous data and that of the next apparition. Specific analysis of the data include completion of long-term drift rates of the Red Spot, a stable atmospheric eddy, and the three White Ovals, decaying eddies. Multicolor images will be reduced and comparisons will be made in an effort to establish the relative heights of belts and zones and the expansion and evolution of specific cloud systems.

d) Summary Bibliography

"Time-Variable Nature of the Jovian Cloud Properties and Thermal Structure: An Observational Perspective". 1989, with G. S. Orton and R. A. West from the Jet Propulsion Lab. NASA Special Publication 494, A chapter in Time-Variable Phenomena in the Jovian System, Edited by M. Belton, R. West and J. Rahe, U.S. Government Printing Press.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

INFRARED SPECTRAL STUDIES OF ASTEROIDS (NAGW-802)

PERFORMING ORGANIZATION Planetary Geosciences Division
Hawaii Institute of Geophysics
University of Hawaii
2525 Correa Road
Honolulu, HI 96822

INVESTIGATOR'S NAME

PI: Jeffrey F. Bell

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

- a) *Strategy:* The research objective is to improve our understanding of the surface mineralogy of asteroids and to link the vast existing body of meteorite geochemical data with specific astronomical objects which may be the targets of future NASA missions. The methodology employed is 1) use advanced astronomical instrumentation to obtain reflection spectra in the 0.3-5.2 μ m wavelength range of selected asteroids; 2) compare the asteroid data with similar data on simulated asteroid regoliths of various compositions to determine the surface mineralogy and meteoritic affinities of asteroid spectral classes and specific asteroids; 3) intergrate the mineralogical information with other astronomical data, orbital dynamics studies, and meteorite geochemistry data to reconstruct the condensational, thermal, and collisional history of the present asteroids and their parent planetesimals; 4) use the information obtained to assist planning of future NASA asteroid missions such as Galileo and CRAF.
- b) *Progress (7/88-2/89):* Completed sections of three review chapters for Arizona Space Science Series book *ASTEROIDS II*; prepared for final publication of *52-Color Asteroid Survey*; continued to observe selected members of the Eos family and other suspected K-class asteroids; provided information for selection of candidate asteroid flyby targets for Galileo and CRAF missions.
- c) *Proposed Research (1989):* Publish 52-color survey spectra; continue to acquire spectra of selected S-type asteroids, Earth-crossers, members of asteroid dynamical families, and suspected K-types; continue to assist planning for Galileo and CRAF mission asteroid flybys; possibly begin observing program in mid-IR.
- d) *Summary Bibliography (1988):* 2 papers published, 4 in press

PUBLICATIONS (NAGW-802):

Piscitelli, J. R., D. P. Cruikshank, and J. F. Bell, "Laboratory Studies of Irradiated Nitrogen-Methane Mixtures: Applications to Triton." *Icarus* **76**, 118-124 (1988).

Bell, J. F., "A Probable Asteroidal Parent Body for the CV or CO Chondrites." *Meteoritics* **23**, 256-257.

Bell, J. F. "Mineralogical Clues to the Origins of Asteroid Dynamical Families." *Icarus*, in press.

Bell, J. F., D. Davis, W. K. Hartmann, and M. J. Gaffey, "Asteroids: The Big Picture." In *ASTEROIDS II*, Univ. of Arizona Space Science Series (in press).

Gaffey, M. J., J. F. Bell, and D. P. Cruikshank, "Reflection Spectroscopy and Asteroid Surface Mineralogy." In *ASTEROIDS II*, Univ. of Arizona Space Science Series (in press).

Chapman, C. R., P. Paolicchi, V. Zappala, R. P. Binzel, and J. F. Bell, "Asteroid Families: Physical Properties and Evolution." In *ASTEROIDS II*, Univ. of Arizona Space Science Series (in press).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

REFLECTANCE SPECTROSCOPY OF PHOBOS AND DEIMOS (NAGW-1383)

PERFORMING ORGANIZATION Planetary Geosciences Division
Hawaii Institute of Geophysics
University of Hawaii
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Honolulu, HI 96822

INVESTIGATOR'S NAME

PI: Jeffrey F. Bell
Co-Is: Jonathan C. Gradie
Paul G. Lucey
David J. Tholen

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

- a) *Strategy:* The objective of the proposed work is to improve our understanding of the surface composition of the satellites of Mars, and to link the data to be obtained by the Soviet "Phobos" spacecraft with the vast existing body of asteroid and meteorite data. The methodology to be employed is: 1) Employ advanced astronomical instrumentation to obtain visual and IR (0.3-3.6 micron) reflection spectra of Phobos and Deimos; 2) Compare the spectra with similar spectra of asteroids to determine if the satellites are in fact captured asteroids, where they originally resided in the asteroid belt, and if the data from the Soviet Phobos mission will tell us anything about the evolution of asteroids; 3) Search for absorption bands due to bound or adsorbed water in clay minerals to determine the value of Phobos and Deimos as fueling bases in future Mars exploration programs; 4) Search for absorption features due to organic molecules to determine the relevance of the Martian satellites to exobiology studies.
- b) *Progress:* Essentially all the proposed observations were carried out at Mauna Kea in September-October 1988, despite severe interference by high clouds. Preliminary analysis of the resulting spectra confirm previous results in that both Phobos and Deimos resemble C-like asteroids at visible wavelengths; however in the JHK region, Deimos exhibits a red slope more characteristic of the P-class asteroids. The 3-micron bound water absorption is very weak or absent in Deimos. No spectral features attributable to organic compounds were found in either satellite. These results suggest that Phobos and Deimos originated in the outer fringes of the asteroid belt. Two abstracts were submitted to the 20th Lunar and Planetary Science Conference.
- c) *Proposed Research:* In 1989-90 we propose to fully reduce the data, present results at several conferences, and prepare manuscripts for publication.
- d) *Summary Bibliography:* 2 LPSC abstracts published

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Photometric and Astrometric Reductions of P/Halley CCD Data

PERFORMING ORGANIZATION

Kitt Peak National Observatory
950 N. Cherry Avenue
Tucson, AZ 85719

INVESTIGATOR'S NAME

Michael J. S. Belton

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

(a) Strategy: The nuclear spin of P/Halley is evidently a complex motion since it has been observationally characterized by two unrelated periodicities. To diagnose the motion and to deduce a precise long-term spin ephemeris we are acquiring photometric time-series of the comets brightness during the post-perihelion phase to as large heliocentric distances as possible. It is our goal to register the apparent variability of the nucleus itself as it spins. This data will be combined with preperihelion data and spacecraft encounter data to yield a precise ephemeris. Such an ephemeris will be the best foundation for relating the observational record of Halley's changing activity to phenomena associated with specific regions on the surface of the nucleus.

(b) Accomplishments (88-89): We have observed Halley as it moved from 5 to 8.5 AU in 1988. We have also obtained time on the KPNO 4-m telescope for further observations in 1989 when the comet will be at 10.6 AU. The photometric reductions are about 50% complete and about 200 images delivered to the IHW Near-nucleus Net. We (with K. Meech) have recovered (as a by-product) P/Kopff (the CRAF target) while it was probably still in its nuclear phase at 4.2 AU and a brightness of approximately 21 (R). We (with A. Ghandi) have developed a new algorithm called "Windowclean" for the extraction of periodicities from our time-series. This was reported at the 1988 DPS (Bull. AAS, 20, 836 (1988)). We have also finished a detailed examination of the determination of the period of Halley from Vega and Giotto data. We have concluded that an earlier assumption regarding the sense of orientation of the long axis of the nucleus at the time of the vega 1 encounter is possibly in error. With the sense reversed the spacecraft data yields a component periodicity to the motion of 3.7 days. This result yields, with the available ground-based data, two possible spin motions. Ways of distinguishing between these based of the recently acquired post-perihelion data is being investigated.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Photometry of Pluto-Charon Mutual Events and Hirayama Family Asteroids

PERFORMING ORGANIZATION

Department of Earth, Atmospheric, and Planetary Science
Massachusetts Institute of Technology
Cambridge, MA 02139

INVESTIGATOR'S NAME

Richard P. Binzel, Principal Investigator

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

Once every 124 years, nature provides earth-bound astronomers with the opportunity to observe occultation and transit phenomena between Pluto and its satellite, Charon. Ground-based observations of these events will allow physical parameters for the Pluto-Charon system to be derived which are unlikely to be improved upon until *in situ* spacecraft observations are obtained. The proposed program will continue to support photometry observations from McDonald Observatory (Fort Davis, TX), a critical location in an international Pluto Campaign network. Knowledge of the diameters, masses, densities, and compositions derived from these observations will augment our understanding of Pluto's origin and its context within the problem of solar system formation.

A second task will continue to research the evolutionary processes which have occurred in the asteroid belt by measuring the physical properties of specific Hirayama family members. Photoelectric lightcurve observations of Koronis and Themis family members will be used to investigate the individual catastrophic collision events which formed each family. By comparing these properties with results of laboratory and numerical experiments, the outcomes of catastrophic disruptions and collisional evolution may be more precisely determined.

During 1988, new photometric observations in B and V filters were obtained during 6 transit events and 2 occultation events using the McDonald Observatory 2.1- and 2.7-m telescopes. Attempts for 2 additional events were completely clouded out. A preliminary analysis of the 1985-1988 data suggests direct evidence for relatively bright polar caps on Pluto. An analysis of the hemispherical color distribution on Pluto and Charon was completed during 1988, with results showing the two bodies have very different, but uniform colors (Binzel 1988a).

Also during 1988, new lightcurve observations were obtained for 11 asteroids, mostly members of the Koronis and Themis families, but also targets of opportunity such as the Galileo spacecraft flyby target 243 Ida. Preliminary reduction of these data was completed, and an extensive analysis of previously obtained Hirayama family data was published (Binzel 1988b).

During 1989, telescope time has been scheduled to attempt observations of 8 Pluto-Charon mutual events using the McDonald Observatory 2.1- and 2.7-m telescopes. Charon and its shadow will be transiting the south polar region of Pluto, allowing information on that surface area to be derived. A detailed analysis of the entire surface albedo distribution using 1985-1989 data is also being initiated.

Also during 1989, 10-20 nights of 1-m telescope time at McDonald and perhaps other observatories will be utilized to obtain additional observations of Koronis and Themis family asteroids. Particular effort will be made to obtain lightcurve observations of Koronis family asteroids at ecliptic longitudes ~90 degrees from previous measurements to test whether their spin vectors have a preferential low obliquity alignment. A preliminary analysis of the 1987-1988 asteroid data will also be conducted.

Publications

Binzel, R.P. (1988a). Hemispherical Color Distributions on Pluto and Charon. *Science* **241**, 1070-1072.

Binzel, R. P. (1988b). Collisional Evolution in the Eos and Koronis Asteroid Families: Observational and Numerical Results. *Icarus* **73**, 303-313.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Studies of Asteroids, Comets, and Jupiter's Outer Satellites, NAGW-1470

PERFORMING ORGANIZATION

Lowell Observatory

INVESTIGATOR'S NAME

Edward Bowell

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

(a) Our work comprises observational, theoretical, and computational research, mainly on asteroids. Two principal areas of research, centering on astrometry and photometry, are interrelated in their aim to study the overall structure of the asteroid belt and the physical and orbital properties of individual asteroids.

(b) We have made excellent progress with LUKAS (the Lowell Observatory-U.K. Schmidt Telescope Asteroid Survey), a deep (limiting $B \sim 22$ mag), bias-correctable survey, the aim of which is to determine the true spatial distribution of asteroids down to subkilometer diameters. Asteroid images have been identified by automatic scanning techniques (with K. S. Russell), using the COSMOS measuring engine in Edinburgh, with a reliability of 98%. In 1988, we used two of three allotted fields to survey the L5 Trojan cloud for faint members; to date, we have identified about 50 new Trojans, thus doubling the known population of the cloud. We have ramped down our survey of photographic astrometry of bright asteroids using the 33-cm Lowell astrograph in favor of a collaboration with E. M. and C. S. Shoemaker, whose films from the 46-cm Palomar Schmidt are greatly superior and much less expensive to acquire (the survey is tentatively named GLAS—the USGS–Lowell Asteroid Survey). We have continued CCD photometry of Chiron, whose nonasteroidal brightness increase we have been monitoring (cf. Bus *et al.* 1989). A review chapter for *Asteroids II* on "Discovery and Follow-up of Asteroids" (Bowell *et al.* 1989a) has been completed. Collaboration with R. P. Binzel to acquire rotational and shape statistics on km-size asteroids continues with CCD observations of two small targets. Theoretical modeling of asteroid brightness variations resulted in two papers (Karttunen 1989; Karttunen and Bowell 1989), and work on a spherical harmonics method of determining asteroid spin vectors (with K. Lumme and others) is nearing completion. A review entitled "Application of Photometric Models to Asteroids" was written for *Asteroids II* (Bowell *et al.* 1989b).

(c) We will focus our astrometric effort in three areas: (1) GLAS. We will explore ways of semiautomatically extracting long-arc orbits for many hundreds of asteroids per year. This will entail the development of new software for the linking of observations, and, probably, a major upgrade of our PDS scanning microdensitometer. (2) LUKAS. We are currently at a stage where as many as 2000 asteroid images can be automatically and rapidly extracted from a single plate; but, as with GLAS, we need software development for linkage and identification that will cope with the rather large data throughput. (3) With K. S. Russell and colleagues at Siding Spring, we will initiate the creation of a special-purpose asteroid positional database. Initially, we will develop a method of extracting asteroid positions from the U.K. Schmidt Sky Survey, which is being digitized. Our CCD astrometry and photometry of selected asteroids (close-Earth-approachers, Chiron, targets for rotational statistics) will continue as last year. Theoretical work on asteroid brightness changes will concern the displacement of an asteroid's photocenter with rotation and phase angle and the modeling of lightcurves of asteroids occulted by the Moon. We are also considering modelling thermal emission from asteroids, account being taken of nonspherical body shape and finite thermal inertia. Work on the spherical harmonics asteroid spin vector method will be completed and submitted for publication. A new project to be pursued (with Lumme and colleagues, U. Helsinki) will be the application of tomography to asteroid photometry; this will have eventual application to *HST* data.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE EVOLUTION OF LARGE-SCALE PLASMA STRUCTURES IN COMETS: KINEMATICS
AND PHYSICS (NAGW-1387)

PERFORMING ORGANIZATION

Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder

INVESTIGATOR'S NAME

John C. Brandt

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

(a) The disconnection event or DE consists of the periodic loss of a comet's entire plasma tail and the growth of a new one. This spectacular phenomenon is not understood. The strategy is to assemble a data base of specific events studied in detail.

(b) This project began on Oct. 1, 1988 and builds on the data (images) gathered as part of the International Halley Watch.

(c) Basic procedures have been refined and a graduate student has been trained. Progress on the DE of Jan. 9-11, 1986 is already substantial in terms of kinematics including the time of disconnection. This event is entirely consistent with the sector-boundary frontside-reconnection picture; in particular, the extrapolated position of the sector boundary, as corrected by IMP-8 measurements, shows a close association with onset of the DE. The results will be ready for publication soon.

(d) The project began on Oct. 1, 1988, but a precursor paper is "The Solar-Wind Interaction with Comets: 1987", by J.C. Brandt and M.B. Niedner, in Proceedings of the Sixth International Solar Wind Conference, Vol 1, p. 347, (NCAR Technical Note; May 1988).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION RESEARCH AND TECHNOLOGY RESUME	
TITLE INFRARED OBSERVATIONS OF SMALL SOLAR-SYSTEM BODIES	
PERFORMING ORGANIZATION JET PROPULSION LABORATORY	
INVESTIGATOR'S NAME R. H. BROWN	
DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)	
<p>a) OBJECTIVES</p> <p>(TASK 1): To measure eclipse disappearance and reappearance curves for the Galilean satellites Europa and Ganymede to determine the penetration scale length for sunlight and thus to determine the extent to which the solid-state greenhouse effect is operating on these two bodies. I will use the IRTF at Mauna Kea Observatory to obtain flux measurements at narrow-band wavelengths of 8.7 and 20 μm during several eclipse disappearances and reappearances of Europa and Ganymede. The measurements will be interpreted using solid-state greenhouse models developed by D. Matson and me.</p> <p>(TASK 2): To measure the reflectance spectra of the icy satellites of Jupiter, Saturn, Uranus and Neptune in the region 2.0 to 2.5 μm using the 32-element InSb photodiode array spectrometer of the IRTF at Mauna Kea Observatory. The specific objective is to search for methane, ammonia and carbon monoxide ices and clathrates on icy surfaces in the outer solar system. The data will allow upper limits to be placed on the amount of these chemical species present. Specific targets are Enceladus, Ariel, Titania, and Triton.</p> <p>b) PROGRESS: A major accomplishment during last year is the recognition of and modeling of the solid-state greenhouse effect for icy satellites. Recent observations of eclipse reappearances suggest that this effect may in fact be observed on Europa and Ganymede. Also the PI has obtained important new data on Europa and Enceladus. Evidence for the transient presence of a volatile, perhaps $\text{NH}_3 \cdot \text{OH}$, on Europa has been obtained; A paper is in press in <i>Icarus</i>. Newly obtained spectra of Enceladus suggest that it does not at present have ammonia or methane in detectable quantities on its surface. A paper is in preparation.</p> <p>c) PROPOSED WORK: First, it is proposed to obtain additional observations of eclipse reappearances and disappearances of Europa and Ganymede, and to extend our existing solid-state greenhouse models to include a surface which is stratified in density. We will use the data and the models to get an estimate of the extent of solid-state greenhousing on Ganymede and Europa. Second, it is proposed to observe Ariel, Dione, Rhea and Titania in the search for volatile surface constituents.</p> <p>d) SUMMARY BIBLIOGRAPHY: Brown, R. H. and D. L. Matson (1987). Thermal effects of insolation propagation into the regoliths of airless bodies. <i>Icarus</i> 72, 84-94; Matson, D. L. and R. H. Brown (1988). Solid-state greenhouses and their implications for icy satellites. <i>Icarus</i> 77, 67-81; Brown, R. H. et al. (1988). Search for volatiles on icy satellites I: Europa. <i>Icarus</i> 74, 262-271.</p>	

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION RESEARCH AND TECHNOLOGY RESUME	
TITLE	Arecibo S-Band Radar Program
PERFORMING ORGANIZATION	National Astronomy and Ionosphere Center Space Sciences Building Cornell University Ithaca, NY 14853
INVESTIGATOR'S NAME	Donald B. Campbell
<p>DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)</p> <p>a) <u>General Objectives</u>: The high powered 12.6cm wavelength radar on the 100-ft Arecibo reflector is utilized for a number of solar system studies. Chief among these are: 1) Surface reflectivity mapping of Venus, Mercury and the Moon. Resolutions achievable on Venus are less than 1.5km over some areas, for Mercury about 30km and for the Moon 200m at present. 2) High time resolution ranging measurements to the surfaces of the terrestrial planets. These measurements are used to obtain height profiles and scattering parameters in the equatorial region. They can also be used to test relativistic and gravitational theories by monitoring the rate of advance of the perihelion of the orbit of Mercury and placing limits on the stability of the gravitational "constant". 3) Measurements of the orbital parameters, figure, spin vector and surface properties of asteroids and comets. 4) Observations of the Galilean Satellites of Jupiter and the satellites of Mars, Phobos and Deimos.</p> <p>b) <u>Past Twelve Months</u>: A very successful set of observations of Venus, made during its close approach in the summer of 1988, is providing high resolution (1.5km) and high sensitivity imagery of low northern latitudes and the southern hemisphere. Eight asteroids were observed including the near earth objects 1685 Toro, 1982 XB, 1980PA and 433 EROS. Ranging measurements were carried out to four of them including Toro and 1980PA. The three icy Galilean satellites were observed in November/December. A detection of Ganymede at 70cm wavelength indicates that its reflection properties at long wavelengths are similar to those at 12 and 3cm. Mars was observed for the first time since the early 1980's and an unsuccessful attempt was made to detect Phobos. There was a small program to study cm-sized space debris in support of the space station project.</p> <p>c) <u>Next Twelve Months</u>: Much of the next year will be taken up with analysis of the 1988 Venus mapping data including production of images over some areas in the polarization parameters of the received signal. These will be compared with results for similar terrains on the earth. Positions of small features in the Venus images from 1988 and earlier years will provide the Magellan project with an improved pole direction. A small number of ranging measurements will be made to Venus. Observations will be made of the Galilean satellites in December aimed at more complete longitudinal coverage, especially of Io. An attempt will be made to measure the reflection properties of Europa at 70cm. Several asteroids will be observed and an attempt will be made to detect Comet Brorsen-Metcalf in August/September. Preparations will be made for a new set of high resolution lunar observations.</p>	

d) Publications:

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

PLANETARY ASTRONOMY (NASW-4266)

PERFORMING ORGANIZATION

Planetary Science Institute (a division of SAIC)
2030 E. Speedway, Suite 201
Tucson, AZ 85719

INVESTIGATOR'S NAME

Dr. Clark R. Chapman

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy: The Planetary Science Institute contract consists of four tasks, and supports six researchers at the Planetary Science Institute (Drs. Campins, Chapman, Davis, Hartmann, Spaute, and Weidenschilling) with some involvement of other staff members. The goal is to use a variety of observational techniques and instruments to reduce, interpret and synthesize groundbased astronomical data concerning the comets, asteroids, and other small bodies of the solar system in order to study the evolution of these bodies.

b. Accomplishments: Task 00: Dr. Chapman co-authored 3 chapters for the "Asteroids II" book, and did additional research on asteroids and small bodies, included in six additional presentations and publications. Task 01: There have been additional photometric geodesy observations and a new manuscript has been prepared for submittal for publication. Task 02: Dr. Hartmann, with his collaborators, has continued his observations and made important discoveries concerning Chiron's anomalous brightening and small Vesta-like Earth-approaching asteroids. Task 03: Dr. Campins' most significant accomplishments on this task include: The completion and publication of the study of Comet Wilson's images; the completion of the reduction of all of the Comet Halley groundbased observations and the submission of these data to the International Halley Watch for publication in the Comet Halley Archives; the successful observation of Comet Tempel 2 in June and September of 1988; and other publications, including a paper on infrared color gradient in the inner coma of Comet Halley and an IAU circular.

c. Anticipated Accomplishments: We will continue in the directions mentioned above, with emphasis on interpretation and synthesis to follow up on the Asteroids II book and the important observational discoveries we have made. Observations will continue at Mauna Kea, Kitt Peak and elsewhere. Among the classes of objects to be observed are various comets, 2060 Chiron, and other asteroids. We will be participating in a variety of scientific workshops and meetings.

d. see attached Summary Bibliography

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

NEAR-INFRARED OBSERVATIONS OF THE VENUS NIGHT SIDE

PERFORMING ORGANIZATION

Jet Propulsion Laboratory

INVESTIGATOR'S NAME

David Crisp

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

Images of the Venus night side at wavelengths near 1.7 and 2.3 microns show bright features that move from east to west, in the direction of the atmospheric super-rotation (Allen and Crawford, 1984). We conducted coordinated near-infrared (NIR) imaging observations of the Venus night side from Kitt Peak and Mauna Kea Observatories to provide a comprehensive description of these features. Thousands of high quality images of Venus were obtained during two-week periods in May and June 1988, before and after Venus passed through inferior conjunction. Some of these images have appeared in Sky and Telescope and The Planetary Report. High-resolution spectroscopic observations were also attempted, but these have not yet yielded usable results. The imaging observations are being used to determine (1) the mechanisms which produce these features, (2) their level of formation, (3) the wind velocities at those levels, and (4) their potential consequences for the Venus "greenhouse" mechanism.

Our preliminary photometric results indicate that the brightest night-side features have 1.74 micron brightness temperatures near 480 K, while the darkest features have brightness temperatures near 425 K at that wavelength. If these features are produced by thermal emission, this emission must originate from levels below 35 km in the Venus atmosphere. The apparent temperature contrast between the bright and dark features is more than an order of magnitude larger than observed horizontal temperature gradients in the Venus troposphere. This suggests that the NIR features are produced by horizontal variations in the atmospheric opacity, rather than horizontal temperature contrasts. The sulfuric acid cloud particles provide the only known source of atmospheric opacity at wavelengths where the features are observed. Our feature tracking results support the hypothesis that these features are formed by horizontal inhomogeneities in the cloud opacity. The rotation period of the features is approximately 6.5 days, indicating equatorial zonal winds near 70 m/sec. The Pioneer Venus probes and the VEGA Balloons measured similar wind velocities in the convectively-unstable middle cloud region (48-58 km). These results indicate that the NIR features are produced as thermal emission from the hot lower atmosphere leaks through partial clearings in the cooler middle or lower cloud decks. A paper describing these results more completely will be submitted to Science later this year.

We are planning to obtain new imaging and spectroscopic observations of the night-side features when Venus passes through inferior conjunction in 1990 and 1991. The 1990 observing period will coincide with the Galileo flyby of Venus. Our ground-based observations will compliment those obtained by the Galileo Nims experiment, which will provide only limited spatial and temporal coverage of the Venus night side. The 1991 observing period will provide the first opportunity to follow up on any important discoveries of the Galileo encounter, and will allow us to assess long-term changes in the night-side NIR features.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Spectroscopic Planetary Detection

PERFORMING ORGANIZATION

Planetary Systems Branch, Code 693
Goddard Space Flight Center, Greenbelt MD 20771

INVESTIGATOR'S NAME

Drake Deming

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy: One of the most promising methods for the detection of extra-solar planets is the spectroscopic method, where a small Doppler shift (~ 10 meters/sec) in the spectrum of the parent star reveals the presence of planetary companions. However, solar-type stars may show spurious Doppler shifts due to surface activity. If these effects are periodic, as is the solar activity cycle, then they may masquerade as planetary companions. The goal of this investigation is to determine whether the solar cycle affects the Doppler stability of integrated sunlight. Observations of integrated sunlight are made in the near infrared ($\sim 2 \mu\text{m}$), using the Kitt Peak McMath Fourier transform spectrometer, with an N_2O gas absorption cell for calibration. We currently achieve an accuracy of ~ 5 meters/sec.

b. Accomplishments: We have been monitoring the apparent velocity of integrated sunlight since 1983. We initially saw a decrease of ~ 30 meters/sec in the integrated light velocity from 1983 through 1985, but in 1987-89 the integrated light velocity returned to its 1983 level. It is too early to say whether these changes are solar-cycle related.

c. Anticipated accomplishments: Wallace et al. (1988, Ap.J. 327, 399) found that the relative wavelengths of lines in integrated light were stable over the solar cycle, and they concluded that planetary companions were detectable. However, in a recent analysis of the extensive Mt. Wilson data, Ulrich and co-workers found evidence for large scale flows with amplitudes up to 50 meters/sec. Since such flows will affect all lines, they will not be seen in relative line shifts, but they may have a significant impact on spectroscopic planetary detection. However, our continued monitoring of integrated sunlight will detect such effects if they are present, since our measurements are absolute. When solar maximum has passed (>1991), we should know whether the changes seen earlier in integrated light velocity are periodic with the solar cycle, and to what extent large scale flows present a limitation to spectroscopic planetary detection.

d. Publications: "On the Apparent Velocity of Integrated Sunlight," D. Deming, F. Espenak, D. E. Jennings, J. W. Brault and J. Wagner 1987, Ap.J. 316, 771-787.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Occultation Studies of the Solar System

PERFORMING ORGANIZATION

Department of Earth, Atmospheric, and Planetary Sciences
Massachusetts Institute of Technology
Cambridge, MA 02139

INVESTIGATOR'S NAME

James L. Elliot

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy: Because of their high spatial resolution, stellar occultations have proven extremely effective for learning about planetary upper atmospheres, asteroids, and planetary rings. Recently — through a combination of ground-based and airborne observations — we have directly detected an atmosphere on Pluto and derived its scale height. Our occultation program at M.I.T. involves (i) identifying the scientific questions that can be answered by occultation events, (ii) predicting the zone of visibility for the useful events, (iii) maintaining and improving a set of portable high-speed photometric systems, (iv) obtaining the observations, and (v) reducing the data and interpreting the results.

b. Accomplishments: Our accomplishments during the past year include (i) a comprehensive analysis of stellar occultation data to establish that Pluto has an atmosphere with a scale height of 59.7 ± 1.5 km. This implies a temperature of 67 ± 6 °K for a pure methane atmosphere or 117 ± 11 °K for a pure nitrogen atmosphere, (ii) the discovery of a haze layer in the atmosphere of Pluto and the development of a model used for occultation data analysis that established that this haze layer is optically thick at Pluto's limb, (iii) the analysis of low-amplitude waves on the edges of the epsilon ring of Uranus; and (iv) the analysis of several hundred CCD "strip scans," obtained over a period of 6 weeks at Mauna Kea for the purpose of generating a prediction for the stellar occultation by Pluto that occurred on June 9, 1988.

c. Anticipated Accomplishments: We are beginning comparative investigation of the atmospheres of Pluto, Titan, and Triton with stellar occultations. The atmospheres of these bodies form a third broad category of planetary atmospheres, considering the other two categories to be terrestrial planet and Jovian planet atmospheres. Identification of these occultations, is in progress, to be followed by observations and analysis. An important part of our program is the development of CCD techniques for occultation predictions and observations.

d. Publications:

French, R.G.; Elliot, J.L.; French, L.M.; Kangas, J.A.; Meech, K.J.; and Ressler, M.E.; Buie, M.W.; Frogel, J.A.; Holberg, J.B.; Fuensalida, J.J.; Joy, M.: Uranian Ring Orbits from Earth-Based and Voyager Occultation Observations. *Icarus* 73, 349-378 (1988).

Baron, R.L.; French, R.G.; Elliot, J.L.: The Oblateness of Uranus at the 1 mbar level. *Icarus*, in press (1989).

Elliot, J.L.; Dunham, E.W.; Bosh, A.S.; Slivan, S.M.; Young, L.A.; Wasserman, L.H.; Millis, R.L.: Pluto's Atmosphere. *Icarus* 77, 148-170 (1989).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Spectroscopy

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona
Tucson, Arizona 85721

INVESTIGATOR'S NAME

Uwe Fink (602) 621-2736

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy: Our effort is divided into instrumentation and observational research. In the area of instrumentation our primary objective is the maintenance and slow improvement of our CCD camera and data acquisition system for continuing use of any interested LPL user. The main goal of our observational research is CCD spectroscopic and imaging studies of the solar system in support of spacecraft investigations. Our studies include the physical behavior of comets, the atmospheres of the gaseous planets, and the solid surfaces of satellites and asteroids.

b. Accomplishments: Our main emphasis during this proposal period was the reduction and analysis of comet P/Halley data. We were able to extract spatial profiles of 1985 Oct., Dec. and 1986 Jan., March and May for emission features of C_2 , NH_2 , [OI], CN and the continuum. These have been analyzed with Haser models and random walk models in collaboration with M. Combi, Graduate student Mike DiSanti completed his Ph.D thesis on the H_2O^+ spatial distribution in comet P/Halley. The data provide quantitative ion density maps and allow a tailward ion acceleration to be extracted. Observationally, we were able to observe two more Pluto/Charon occultation events and were able to get a reflectance spectrum of the Martian satellite Deimos. Our instrumentation was also heavily used for observations of Mars (R. Singer et al), Mercury (D. Hunten, A. Tyler et al) and Jupiter (M. Tomasko, D. Hunten, K. Wells, E. Karkoschka).

c. Anticipated Accomplishments: We are planning to continue our reduction of P/Halley data to determine the comets water production rate as a function of heliocentric distance. We will also determine the production rate behavior of C_2 , CN and NH_2 with respect to the water production. Observationally, we will continue to observe periodic and new comets as they become available and determine any possible differences in chemical composition between them. We have made a good start in this by obtaining spectra of Yanaka 1988r, 1989a, Shoemaker 1989e, 1989f and P/Clark. We also need to make continued improvement and upgrades to our CCD camera and data acquisition system.

d. Publications

U. Fink and M. DiSanti, "The separate spectra of Pluto and its satellite Charon," *Astron. J.*, 95, 229-236 (1987).

R. L. Marcialis, E. F. Tedesco, L. A. Lebofsky and U. Fink, "The albedos of Pluto and Charon: Wavelength dependence," 20th Annual DPS/AAS meeting, Austin, Texas, Oct 31 - Nov 3, *BAAS*, 20, 807 (1988).

U. Fink, M. DiSanti, A. Schultz and M. Combi, "Emission profiles for comet P/Halley," 20th Annual DPS/AAS meeting, Austin, Texas, Oct 31 - Nov 3, *BAAS*, 20, 828 (1988).

M. DiSanti, U. Fink and A. Schultz, "Spatial distribution of H_2O^+ ions in comet P/Halley," 20th Annual DPS/AAS meeting, Austin, Texas, Oct 31 - Nov 3, *BAAS*, 20, 829 (1988).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

CCD Photometry of Trojan Asteroids

PERFORMING ORGANIZATION

Lowell Observatory

INVESTIGATOR'S NAME

Linda M. French

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a.) The composition and collisional evolution of Trojan asteroids differ significantly from those of main belt asteroids. Systematic surveys of rotation parameters can yield information about initial formation and subsequent collisional modification. CCD detectors and 1-2 meter-sized telescopes are being used to obtain light curves and phase curves of Trojan asteroids and to monitor the photometric behavior of 2060 Chiron. A search for new Trojans in the L5 group is underway using the 24" Curtis Schmidt Telescope of the Cerro Tololo Interamerican Observatory.

b.) New lightcurves have been obtained for 5 Trojan asteroids. Plates covering ~10% of the known Trojan region have revealed 37 new Trojans in the L5 group; orbits have been derived from 60-day arcs and will be used to recover the asteroids from CTIO during their 1989 opposition. In late 1988, the amplitude of the lightcurve of 2060 Chiron was only half its value in 1986, suggesting that the object may be undergoing cometary-type activity.

c.) The new Trojans will be recovered from CTIO, and telescope time at CTIO and Lowell Observatory will be requested to obtain photometry of previously known Trojans as well as the smaller new objects, in order to extend our knowledge of Trojan rotation properties to smaller objects. The IRAS data set of observations of previously unknown asteroids (the "Fishpond") will be searched for possible matches in order to derive diameters and albedos of the new Trojans.

d.) Bibliography:

1. "New CCD Lightcurves of Trojan Asteroids" by L. M. French, R. G. French, and S. J. Olmsted. *B.A.A.S.* **20**, 853, 1988.
2. "2060 Chiron" by S. J. Bus, E. Bowell, and L. M. French. IAU Circular 4684, 5 December 1988.
3. "A Search for Asteroids in the L5 Trojan Cloud" by L. M. French, E. Bowell, S. J. Bus, K. Russell, C. Shoemaker, and E. Shoemaker. *Comets, Meteors, Asteroids III*, in press, 1989.
4. "Distant Asteroids and Chiron" by L. M. French, F. Vilas, W. K. Hartmann, and D. J. Tholen. In *Asteroids II*, (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.), Univ. of Arizona Press, in press.
5. "Charge-Coupled Device Photometry of Asteroids" by L. M. French and R. P. Binzel. In *Asteroids II*, (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.), Univ. of Arizona Press, in press.

Articles in Refereed Publications:

1. "Distant Asteroids and Chiron" by L. M. French, F. Vilas, W. K. Hartmann, and D. J. Tholen. In *Asteroids II*, (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.), Univ. of Arizona Press, in press.
2. "Charge-Coupled Device Photometry of Asteroids" by L. M. French and R. P. Binzel. In *Asteroids II*, (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.), Univ. of Arizona Press, in press.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

CCD Scanning for Comets and Asteroids

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory and Steward Observatory
University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Tom Gehrels

a. Strategy: Some populations of objects in the solar system are still poorly known, and the long-range goal of this program is to improve that situation. For instance, the statistics of Trojan asteroids are uncertain, while previous surveying indicates there is an appreciable systematic difference between the L-4 and L-5 regions. We are therefore developing new techniques of sky surveillance, primarily by scanning with CCD.

b. Accomplishments: A 320 x 512 pixel CCD has been in operation since 1983 on a telescope that is dedicated during the dark half of each month to sky surveillance, namely the Spacewatch Telescope which is the 91-cm Newtonian reflector of the Steward Observatory on Kitt Peak. The preparations included extensive computer programming for automatic detection of moving objects and for processing in real time. New asteroids are readily found, but we have chosen to follow with astrometry only a few of them that are of special interest: a Trojan, a Hilda-type, a 2:3 resonance asteroid, and a few Hungarias. The astrometry proves to be especially valuable. The telescope drive is turned off at a selected distance west of the object and the scan is continued such that the number of astrometric standards is optimized. It is in principle a transit technique, but that can be applied anywhere in the sky and not merely in the meridian. The precision turns out to be better, by nearly a factor of 2, than what is usually done for asteroids and comets. Astrometry has been done particularly for new discoveries by other astronomers and in order to facilitate radar observations. Some 1400 observations have been published to date in the Minor Planet Circulars; comet recoveries are in the I.A.U. Circulars.

A 2048 x 2048 Tektronix CCD has been installed at the f/5 focus of the Spacewatch Telescope. In a cooperative program with the Indian Institute of Astrophysics (Rajamohan et al. 1987, 1988a, 1988b) a 385 x 576 CCD is being tested in the scanning mode at the 30-inch reflector of the Kavalur Observatory. These programs, as well as the early days of planetary sciences and NASA's space program, have been described by Gehrels (1988).

c. Anticipated Accomplishments: The 2048 x 2048 Spacewatch CCD is gradually coming on-line with new software and hardware for automatic data processing on Trojans, comets, and near-Earth asteroids. The program in India is moving towards a dedicated 127-cm CCD-scanning telescope.

d. Publications: Gehrels, T., On the Glassy Sea: An Astronomer's Journey (New York: American Institute of Physics), 349 pp., 1988.
Rajamohan, R., Bhattacharyya, J. C., Kuppuswamy, K., and Paranjpye, A., 1987, "Project Kalki - a Sky Survey with the Schmidt Telescope - 1", Bull. Astron. Soc. India, 15, 174.
Rajamohan, R., Shankar, P. N., Bhattacharyya, J. C., Kuppuswamy, K., and Paranjpye, A., 1988a, "Project Kalki - a Sky Survey with the Schmidt Telescope - 2", Bull. Astron. Soc. India, 16, 21.
Rajamohan, R. et al. 1988b, "Project Kalki - Tests with a Scanning CCD", Bull. Astron. Soc. India (in preparation).

National Aeronautics and Space Administration
RESEARCH AND TECHNOLOGY RESUME

Title: HIGH-RESOLUTION IMAGING OF SOLAR SYSTEM OBJECTS

Performing Organization: Jet Propulsion Laboratory, Caltech

Investigator's Name: Bruce A. Goldberg

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. The short-term strategy is to complete the analysis and publication of extensive cometary and Io sodium cloud data sets acquired during the period 1976-87. Optical-wavelength LLTV sensor systems were employed at three groundbased observatories for data acquisition. Much of the data reduction has been completed at JPL's Image Processing Laboratory (IPL). Some of the observational highlights are (i) high-resolution CCD images of comets Halley and Giacobini-Zinner (GZ) obtained with the 3.6m Canada-France-Hawaii Telescope (CFHT) on Mauna Kea, the latter constituting the only high quality imagery obtained during the encounter period of the International Cometary Explorer (ICE) spacecraft with this comet; (ii) the first 2-D images of Io's neutral sodium cloud and the results of a unique imaging program which was continued at JPL's Table Mountain Observatory (TMO) through the Voyager encounters with Jupiter; and (iii) images of Halley taken with extreme time resolution at AMOS Observatory on Haleakala, Maui.

The longer-term scenario includes continued refinement of measurement and data analysis capabilities at AMOS. This work will technically enhance the potential for future astronomical observations at this facility. However, it is currently not driven by NASA needs nor is it supported by NASA funding.

b. Analysis of CFHT comet data continued. Key CFHT observations of GZ were reduced and submitted to the IHW archive. The AMOS program noted above, which will hopefully have application to future NASA-supported planetary programs, continued with USAF funding. Much-reduced NASA funding for FY88 was used primarily to absorb a deficit carried over from FY87, and to serve as a source of carryover funds into FY89 to allow continued use of IPL for analysis of CFHT comet data.

c. NASA funding was not continued in FY89. However, the PI is continuing with the analysis of CFHT comet data (at personal expense) together with principal collaborators R.J. Bamberg (JPL), I. Halliday and B.A. McIntosh (Herzberg Inst. of Astrophys., Ottawa), G.C.L. Aikman (Dominion Astrophys. Obs., Victoria), and A.F. Cook (Harvard-Smithsonian C.F.A.). None of these collaborators is funded by NASA. Both the CFHT and DAO have offered facilities and computing support. The primary objective for FY89 is to complete the analysis of specific components of the CFHT data set and proceed with the publication of the corresponding results. Two papers have been submitted for the meeting "Comets in the Post-Halley Era" to be held in Bamberg, Germany in April 1989.

Analysis of the Io sodium data set is being continued by W.H. Smyth of AER, Inc. with funding from the Planetary Atmospheres Program.

d. Goldberg, B.A. et al. 1984, "Io's Neutral Sodium Cloud", Science 226, 512-516 & cover; Slavin, J.A., Goldberg, B.A. et al. 1986, "The Structure of a Cometary Type I Tail: Groundbased and ICE Observations of P/Giacobini-Zinner", Geophys. Res. Lett. 13, 1085-1088 (also included with cover illustration in Comet Encounters 1988, Birmingham and Dessler, Editors, Publ. AGU); Goldberg, B.A. et al. 1986, "High-Resolution Imaging Studies of the Near-Nucleus Regions of Comets", Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet, Heidelberg, ESA SP-250, 153-156; Goldberg, B.A. et al. 1989, "Cometary Analysis in the Post-Halley Era (I): Correlation of Groundbased and Spacecraft Measurements to Obtain New Information about the Structure and Behavior of the Ion and Dust Tails" and Goldberg et al. 1989, "Cometary Analysis in the Post-Halley Era (II): Utilization of Multidimensional, High-Resolution Imaging Data Sets for Analysis of the Physical Properties of the Nucleus and Inner Coma", both submitted for presentation at the colloquium "Comets in the Post-Halley Era", Bamberg, FRG, April 1989.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

SUBMILLIMETER HETERODYNE RECEIVER FOR THE CSO TELESCOPE

PERFORMING ORGANIZATION

JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CA 91109

INVESTIGATOR'S NAME

Gulkis, S.

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

- a. **Strategy:** This task is to build a cryogenically cooled 620-700 GHz astronomical receiver that will be used as a facility instrument at the CalTech Submillimeter Observatory on Mauna Kea, Hawaii. The receiver will have applications as a very high resolution spectrometer to investigate spectral lines in planetary and satellite atmospheres, and comets. The receiver will also be used to make continuum measurements of planets, satellites, and asteroids.
- b. **Accomplishments:** A Solid state oscillator that covers two bands in the 600-700 GHz range was developed under contract and delivered to JPL. The oscillator uses a 110 GHz Gunn oscillator, along with a frequency tripler and doubler to provide LO power in the 620 GHz and 690 GHz frequency range. Testing and optimization are currently taking place. The 600-700 GHz mixer block has been designed and sent to the shop for fabrication. SIS junctions are being tested using the test hardware assembled in previous years.
- c. **Anticipated Accomplishments:** The major effort during FY89 will be to integrate a 600 GHz SIS mixer into the cryostat and to optimize the system for use as a spectral line receiving system on the CalTech Submillimeter Telescope.
- d. **Publications:** Gulkis, S., Frerking, M.A., Swanson, P.N., Wannier, P., and Wilson, W.J.: Submillimeter Heterodyne Receiver for the CalTech Submillimeter Telescope on Mauna Kea: proposal submitted to the NASA Aeronautics and Space Administration Office of Space and Application.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Research in Planetary Studies and Operation of Mauna Kea Observatory

PERFORMING ORGANIZATION

University of Hawaii at Manoa
Institute for Astronomy
Honolulu, Hawaii

INVESTIGATOR'S NAME

Donald N.B. Hall
Institute for Astronomy
2680 Woodlawn Drive
Honolulu, Hawaii 96822
(808) 948-8566

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a) This investigation concentrates on observational and interpretational studies of solar system bodies, the planets, their satellites, the asteroids and comets. Observations are made at all visual wavelengths and in the infrared using the telescopes and instruments at the Mauna Kea Observatories. The prime telescope for this work is the NASA-built 2.24-m telescope of the University of Hawaii.

b) Principal accomplishments of this grant in the interval from July 1987 through June 1988 include: i) a determination of the rotation period of Neptune from measurements on a bright cloud at latitude 38 degrees south, ii) a brightness upper limit of 18th mag arcsec⁻² was found for the putative ring arcs about Neptune at a wavelength of 2.2 μ m, iii) measurement by infrared polarisation of volcanic activity in or near to the Amirani/Maui and Loki volcanoes on Io, iv) tentative identification of CH stretch absorption features at 3.39 and 3.50 μ m in the spectra of asteroids 19 Fortuna and 65 Cybele, v) acquisition of images of the thermal emission from the dark side of Venus near to inferior conjunction which show striking cloud features with fine structure of the order of 400 - 500 km, vi) observations of 13 comets at a variety of heliocentric distances for modelling their activity as a function of distance, vi) observations of comet P/Halley to understand its rotational dynamics, vii) acquisition of rotational light curve data for comets P/Tempel 2 and P/Schwassmann Wachmann 1, viii) discovery that the nucleus of comet Wilson had split, ix) discovery of an outburst in asteroid 2060 Chiron, x) the first 3 - 4 μ m spectrum of Triton was obtained, xi) observation of the phase function of Triton, xii) theoretical modelling of the thermal emission of asteroids including surface roughness was shown to lead to systematic biases that lead to radiometric diameters in error by up to 20%, and xiii) from observations of many more Pluto/Charon mutual events, the errors in the orbital and physical parameters have been decreased by a factor of two or more.

c) Work proposed for the coming year will follow up many of the discoveries made the past year and press hard on work with some new capabilities that are appropriate for planetary research. We will follow up on the discovery of activity of 2060 Chiron, we will continue the observation of Pluto/Charon mutual events since they are equal in importance to those that have already been observed, we will continue with studies of the volcanism of Io and press toward preparations for the spectacular 1990/91 series of occultations of Io, and we will continue to push the application of the infrared array detectors to fruitful imaging of planetary objects. In addition to these continuing projects, we anticipate taking on new tasks as led by our post docs and graduate students. In particular, theoretical studies will be pressed on the internal constitution of comets (J. Greene), the possibility that Valles Marineris originated by chemical dissolution of subsurface materials (Spencer), the analysis of thermal emission from rough surfaces on Ganymede and Callisto, and the absorption spectrum of organics on comets and asteroids will be followed up by careful laboratory work (Piscitelli) are all new projects to be undertaken. No doubt that our new staff member, David Jewitt, will be bringing new research projects as well. Other continuing programs will be carried out on rotation of comets and modelling their brightness versus heliocentric distance variations. Lastly, the 2.24-m telescope will be continued to be used for planetary studies for at least 30% of the time by planetary people at Planetary Geosciences Division, outside astronomers, and the Institute's planetary astronomers.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

INFRARED OBSERVATIONS OF PERIODIC COMETS

PERFORMING ORGANIZATION

JET PROPULSION LABORATORY

INVESTIGATOR'S NAME

MARTHA S. HANNER

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a). Selected comets are observed in the infrared with the NASA IRTF and other telescopes as appropriate. The scientific objectives are to characterize the thermal emission from the dust coma, derive dust production rates, study the silicate features near 10 and 20 microns, and detect changes in grain size or composition with heliocentric distance as well as differences among comets. In a few cases of low dust activity, the comet nucleus can be directly detected in the infrared and its size and albedo determined.

b). Accomplishments: 24 comets have been observed under this program. The data base is being used to obtain the average properties of comet dust and to derive as much physical information as possible about selected individual comets. Accomplishments in the past year include. 1) Workshop report was completed on Infrared Observations of Comets Halley and Wilson and Properties of the Grains, (NASA CP-3004, ed. M. Hanner). 2) Comet P/Tempel 2 was observed at perihelion at the IRTF. 3) CVF spectrum of silicate feature in Comet Bradfield (1987s) at $r = 1.45$ AU was obtained, showing an 11.3 micron peak similar to Halley. Paper has been written, including both IRTF and UMinn data. 4) Paper on Comet Wilson (1986g) was prepared (Hanner & Newburn, Astron. J., Jan. 1989), comparing Wilson at $r = 1.36$ and 3.75 AU. Dust albedo was higher at larger r , and H-K color was bluer.

c). 1989 Plans: 1) Evolution of the silicate feature in Comet Halley will be studied; reanalysis of IRTF and other data indicates 10 micron silicate emission was still present at 2 AU. 2) Review of infrared observational techniques will be prepared for Bamberg Comet Conference and subsequent book. 3) Comet observations will continue at the IRTF, including P/Brorsen-Metcalf, with orbit similar to Halley 4) Paper comparing dust properties in comets will be prepared.

d). Publications:

Hanner, M. S., ed (1988). Infrared Observations of Comets Halley and Wilson and Properties of the Grains. NASA Conference Publication, 3004.

Publications During 1988

Hanner, M. S. (1988). Chapter 2: Grain Optical Constants. In Infrared Observations of Comets Halley and Wilson and Properties of the Grains. ed. M. S. Hanner, NASA Conference Publication 3004, p. 22-49.

Tokunaga, A. T., Golisch, W. F., Griep, D. M., Kaminski, C. D., and Hanner, M. S. (1988). The NASA Infrared Telescope Facility Comet Halley Monitoring Program II. Postperihelion Results. Astron. J. 96, 1971-76.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Table Mountain Observatory Support to other programs

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

Alan W. Harris

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. The Table Mountain Observatory (TMO) facilities include well equipped 24" and 16" telescopes with a 40" (1m) telescope (owned by Pomona College), and a 48 inch (1.2m) telescope, due for completion during FY 90. This proposal is to provide operational support (equipment maintenance, setup, and observing assistance) at TMO to other programs.

b. The program currently most heavily supported by this grant is the asteroid photometry program directed by A. Harris. During 1988, about 20 asteroids were observed. The photometric observations are used to derive rotation periods, estimate shapes and pole orientations, and to define the phase relations of asteroids. The E class asteroid 64 Angelina was observed, and showed the same "opposition spike" observed of 44 Nysa, last year. Comet observations are made with the narrow band camera system of David Rees, University College London. Observational support and training was provided to students and faculty from the Claremont Colleges for variable star observing programs.

c. We propose to continue the asteroid program, with emphasis on measuring phase relations of low and high albedo asteroids at very low phase angles, and supporting collaborative studies of asteroid shapes. Efforts will be made to observe occultations by asteroids, and to obtain lightcurves so that the rotation phase at the time of occultation will be known. Asteroids which are planned for radar observations will be given special attention, as the combination of radar and photometric data is much more valuable than either observation separately. The Rees narrow band camera is at TMO and will be used as comet targets become available. Other observing programs will be supported as scheduled on the telescopes, as resources permit.

1) Harris, A.W. and J.W. Young (1988) Two dark asteroids with very small opposition effects. Lunar and Planetary Science XIX, 447-448. 2) Harris, A.W., and 10 co-authors (1989). Photoelectric observations of asteroids 3, 24, 60, 261, and 863. Icarus, in press. 3) Harris, A.W. and J.W. Young (1988) Asteroid lightcurve observations from 1979-1981. Icarus, in press. 4) Harris, A.W., and 11 co-authors (1989). Phase relations of high albedo asteroids: 44 Nysa and 64 Angelina. Icarus, submitted.

Table Mountain Observatory Support to other programs

PI: A. W. Harris, JPL

Publications in FY 88:

- Harris, A.W. and J.W. Young (1988) Two dark asteroids with very small opposition effects. Lunar and Planetary Science XIX, 447-448.
- Harris, A.W., and 10 co-authors (1989). Photoelectric observations of asteroids 3, 24, 60, 261, and 863. Icarus, in press.
- Harris, A.W. and J.W. Young (1988) Asteroid lightcurve observations from 1979-1981. Icarus, in press.
- Harris, A.W., and 11 co-authors (1989). Phase relations of high albedo asteroids: 44 Nysa and 64 Angelina. Icarus, submitted.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Palomar Planet-Crossing Asteroid Survey (PCAS)

PERFORMING ORGANIZATION

Geology and Planetology Section
Mail Stop 183-501
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91109

INVESTIGATOR'S NAME

Eleanor F. Helin

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

A. STRATEGY:

A systematic survey for planet-crossing asteroids is being conducted with the 0.46 m Schmidt at Palomar to increase the number of known asteroids and establish improved estimates of their populations and size distribution. A very limited number of PSSII plates from the 1.2 m Schmidt are also used to search for unusual objects. Field pairs from the 0.46 m are inspected with a stereomicroscope; new objects are detected and followed to establish definitive orbits. When near-Earth asteroids are discovered, other astronomers are informed so that physical observations can be obtained. With remote sensing results, possible generic relationships are suggested. Population refinements can be accomplished by increasing the number of known asteroids under well-established conditions of search.

B. ACCOMPLISHMENTS:

From January 1988 through the present, 201 asteroids were discovered and reported. Over 75 have good orbits for future observations. Significant discoveries include Apollo 1988 EG, Amor 1988 PA, independent discovery of Apollo 1989 AC, 9 Mars-crossers and Mars-grazers, 21 high-inclination objects: 9 Hungaria and 10 Phocaea region asteroids, as well as 1988 EO and 1988 RH, both having inclination exceeding 30 degrees occupying unique positions in phase space. Distant short-period Comet Helin-Roman-Crockett, P/1989b was discovered. It has a period of 8.12 years and an unusually low inclination and eccentricity which with its large perihelion at 3.47 AU makes it continuously observable. Thirteen asteroids have been permanently numbered: 3 near-Earth asteroids (3752) (3757) and (3988), as well as unique Mars-crosser (3800).

C. ANTICIPATED ACCOMPLISHMENTS:

As well as an effort to expand our sky coverage, emphasis has also been placed on adequate follow-up of newly-discovered objects to provide necessary data for more accurate orbit determination. Additional members have joined our INAS program and will be contributing as collaborators worldwide to the expansion of sky searched in the detection of near-Earth asteroids and comets. Special focus continues on the identification of high-inclination asteroids and slow-moving distant objects.

P U B L I C A T I O N S

Planet-Crossing Asteroid Survey (PCAS)

- Helin, E. F. (April 1988) Gli Asteroidi Vicini, Astronomia No. 76, pg 30-38.
- Helin, E. F. (1988) Discovery, Recovery and Physical Observations of (3757) 1982 XB; A Prime Mission Candidate, Asteroids II Conference, Tucson, abstract.
- Helin, E. F., R. S. Dunbar, E. M. Shoemaker, C. S. Shoemaker, and T. Gehrels, 1988, Search Techniques for Near-Earth Asteroids, chapter contribution to Asteroids II submitted.
- Helin, Eleanor (1988) Asteroid Search Program, JPL Highlights, 1988.
- Helin, E. F. (1988) Interesting Dynamical Aspects of 1989b, a New Short-Period Comet, Lunar and Planetary Science Conference XX Proceedings, Part I March, 1989.
- Helin, Eleanor F. (1989) High-Inclination, Inner-Belt Asteroids: Increased Data Base, to be published in Asteroids, Comets and Meteors III Meetings, Uppsala, Sweden, June 1989.
- Pierce, David [E. F. Helin] (1989) The Hollow Asteroid, 1989 EG, submitted to Astronomy Magazine.

Discovery and Astrometric Position Publications

International Astronomical Union Circulars:

- 1988: 1988b, IAU Circ No 4548; 1988 EG, IAU Circ No 4565, 4571, 4573, 4639, 4642, and 4655.
- 1989: 4699, 4701, 4702, 4704, 4705, 4715, 4722, 4737.

Minor Planet Circulars:

- 1988: MPC Nos 12652, 12766, 12910, 13019-020, 13035, 13132, 13236-237, 13305, 13392-398, 13461-462, 13480-484, 13537-538, 13665-668, 13814-815, 13983-985.
- 1989: MPC Data available on disk, but we do not as yet have a hard copy with references only

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE Extreme and Far Ultraviolet Astronomical Observations with the
Voyager Ultraviolet Spectrometers

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona

INVESTIGATOR'S NAME

Jay B. Holberg and Ronald S. Polidan

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a) *Strategy:* This research involves the analysis and interpretation of observations obtained with the Voyager ultraviolet spectrometers during periods of interplanetary cruise. These observations include spectra of stellar and non-stellar sources at wavelengths shortward of 1200 Å. Voyager observations are currently the only available means of obtaining such data.

b) *Progress 1988/89:* During the past year observations have been obtained of a number of sources including: 1) The first observations of the Vela supernova remnant shortward of 1200 Å, which exhibits a diffuse line emission spectrum considerably different from earlier Voyager spectra of the Cygnus Loop remnant. 2) EUV ($\lambda < 900$ Å) observations of the nearby B star Beta CMa have been used to place an interesting lower limit on the column density of neutral H to this star. 3) EUV observations of several cataclysmic variables have been reported². In the case of one of these, VW Hyi, it appears that upper limits derived from Voyager observations can be used to seriously constrain models in which the bulk of the outburst luminosity is emitted in the EUV. 4) Observations of the Beta Cephei star ν Eri have shown that the 1050 Å light curve exhibits an instability near the phase of maximum light. 5) Observations were obtained of a number of Active Galactic Nuclei (AGNs). These included Markarian 335, 509, 841, 1383, NGC 5548, PG 1211+143 and 3C 273. Most of these observations were done simultaneously with IUE and ground-based observations. The results for Markarian 509 show dramatic variability shortward of 1200 Å. 6) A review¹ of the results obtained by Voyager in the EUV was presented at the Berkeley Symposium on EUV Astronomy.

c) *Anticipated Accomplishments:* In the coming year we anticipate major efforts in the following areas. 1) The FUV sky background. Systematic investigations are now underway in an effort to determine the nature of the residual 900 to 1200 Å signal seen at low galactic latitudes with Voyager. Preliminary results will be presented at the IAU Symposium (No. 139) on Galactic and Extragalactic Background Radiation in Heidelberg in June 1989. 2) A catalogue of Voyager absolute fluxes for a set of luminous and subluminous standard stars is now in preparation. 3) A study of the limits on EUV emission from several nearby, hot B stars is currently underway. 4) NGC 5548 will be continually monitored as part of the world-wide campaign to monitor this AGN with the UVS, IUE and ground-based observations. We also plan to observe the BL Lac object PKS 2155-304 as well as a number of other bright, nearby AGNs. Our objective is to characterize the variability of these objects shortward of 1200 Å.

d) *Bibliography:* (attached)

d) *Summary Bibliography.*

- 1) Holberg, J. B., "EUV Results from Voyager," *Extreme Ultraviolet Astronomy*, R. Molina ed. (in press) 1989.
- 2) Polidan, R. S., and Mauche, "EUV Emission from Cataclysmic Variables," in *Extreme Ultraviolet Astronomy*, R. Molina ed. (in press) 1989.
- 3) Polidan, R. S., Stalio, R., and Peters, G. J., "Voyager Observations of Be Stars. I. Flux Distributions, Gravity Darkening and Flux Variability," *Ap.J.* (in press) 1989.
- 4) Long, R., Stalio, R., Polidan, R. S., and Rossi, L., 1988 *Ap.J* (in press) 1989.
- 5) Polidan, R. S., "A New Study of the Interacting Binary Star V356 SGR," in *A Decade of UV Astronomy with IUE*, ESA SP-281 1988.
- 6) Reichert, G. A., Polidan, R. S., C. C. Wu, and Carone, T.E., "Voyager and IUE Observations of 3C 273: Detection of Possible Lyman Continuum Absorption in a Nearby ($z=0.158$) Quasar." *Ap.J.* , 325, 671-678 (1988).
- 7) Polidan, R. S., "500-3200Å Observations of the Interacting Binary Star V356 Sgr. and β Lyr," in *Algols*, ed. A. H. Batten (in press) 1989.
- 8) Carone, T. E., and Malkan, M. A., "Voyager Far UV Observations of Markarian 509," in *Proceedings of the Georgia State University Conference on Active Galactic Nuclei*, eds. H. Richard, p. 52., 1988.
- 9) Poulin, E., Wesemael, F., Fontaine, G., and Holberg, J. B., "A Comparative Study of Two DO White Dwarfs," in *Proceedings of the IAU Colloquium No.114, White Dwarfs*, G. Wegner ed. 1989.
- 10) Carone, T. E., and Malkan, M. A., "Voyager Far UV Observations of Markarian 509," *Proceedings of the Georgia State University Conference on Active Galactic Nuclei*, eds. H. Richard, Miller and Paul J. Wiita, Springer-Verlag, 1988.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Infrared Speckle Interferometry and Spectroscopy of Io

PERFORMING ORGANIZATION

University of Wyoming

INVESTIGATOR'S NAME

Robert R. Howell

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography.)

a) The principal goal of this project is to determine the locations, temperatures, and lifetimes of volcanic hot spots on Jupiter's moon Io, using the technique of infrared speckle interferometry. In addition, the distribution and state of materials (SO_2 and H_2S) related to the volcanism are being determined by speckle observations and conventional spectroscopy.

b) During the past year speckle observations from the 1987 opposition of Jupiter were reduced, and monitoring for the 1988 opposition was begun. For several months on each side of opposition approximately one week of observing time per month was allocated to this program on the Wyoming 2.3 meter telescope. In particular, observations were obtained during the Jupiter Watch Weeks in September and November, in coordination with work by others.

The speckle observations show continued changes in the activity on Io. Relatively minor hot spots have been seen at new locations during 1987, and apparently during 1988. Preliminary reduction indicates that these are at low temperatures, and also low latitudes. The 5 micron flux from the Loki hot spot, which was low in 1987, has increased, although not to the levels of 1984 and earlier. Multichannel instrumentation which we hope to use during the 1991 mutual events was tested.

The new spectroscopic observations planned for this year were thwarted by poor observing weather, but D. Nash's analysis of spectra we had previously obtained shows possible evidence for H_2S frost on the surface of Io. The presence of H_2S frost and an accompanying atmosphere could explain several puzzles such as the dark color of the polar regions.

c) A major goal for the coming year is to improve the statistics on the locations of hot spots, in particular the relative frequency of high latitude vs. low latitude events. Changes have just been made in the instrument which enable us to investigate the latitudinal distribution of SO_2 frost using speckle observations in narrow band filters. In addition, we will obtain observations relating to the possible presence of the H_2S . Finally, we hope to complete the spectroscopic observations related to the presence of the SO_2 atmosphere.

d) Goguen et al. Io Hot Spots: Infrared Photometry of Satellite Occultations. Icarus 76: 465-484.

Howell et al. High Resolution Infrared Spectroscopy of Io and Possible Surface Materials. Icarus in press.

Goguen et al. Io Hot Spots: Satellite Occultations of Sources. Submitted to Icarus.

Nash & Howell H_2S on Io: Evidence from Telescopic and Laboratory Infrared Spectra. Submitted to Science.

Papers published or submitted in 1988

- "High Resolution Infrared Spectroscopy of Io and Possible Surface Materials."
R. R. Howell, D. B. Nash, T. R. Geballe, and D. P. Cruikshank
Icarus in press.
- "H₂S on Io: Evidence from Telescopic and Laboratory Infrared Spectra."
D. B. Nash and R. R. Howell Submitted to Science.
- "Io and Europa: The Observational Evidence for Variability."
R. R. Howell and W. M. Sinton In special NASA publication "Time
Variable Phenomena in the Jovian System".
- "Io Hot Spots: Infrared Photometry of Satellite Occultations."
J.D. Goguen, W. M. Sinton, D. L. Matson, R. R. Howell, H. M. Dyck, T. V.
Johnson, R. H. Brown, G. J. Veeder, A. L. Lane, R. M. Nelson, and R. A.
McLaren Icarus 76: 465-484.
- "Io Hot Spots: Satellite Occultations of Sources."
J.D. Goguen, W. M. Sinton, D. L. Matson, R. R. Howell, H. M. Dyck, T. V.
Johnson, R. H. Brown, G. J. Veeder, A. L. Lane, R. M. Nelson, and R. A.
McLaren Submitted to Icarus.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Studies of Extended Planetary Atmospheres (NAGW-596)

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
The University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Donald M. Hunten

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Spectroscopic observations of gases and plasmas in the Jupiter system, and related phenomena such as the recently-discovered sodium atmospheres of Mercury and the Moon. Occultation studies. Observations of other planets as opportunities arise.

b. The data set on Mercurian sodium and potassium is mostly analyzed, along with IR reflectance spectra obtained at the IRTF.

Lunar sodium has been observed; the scale height is around 79 km, as expected, but the density is very small, 1/400 of the Mercury value. This large difference points to an origin within the regolith, with the supply rate to the surface controlled by diffusion along grain boundaries and through the regolith pores.

Water vapor on Mars has been mapped in a collaborative program with a group at GSFC observing ozone by heterodyne spectroscopy. The seasonal variations are also being pursued; several successful runs have been completed, and it is clear that the Viking year was not necessarily typical.

Data pertaining to lightning and aurora on Venus are still in the analysis process; no positive results have been obtained yet.

A Neptune occultation was observed at the MMT in collaboration with Hubbard and G. and M. Rieke. Excellent data were obtained, but there is no secure evidence of any ring arcs. This was the first field use of the IR (chopped) mode of the new data systems.

Hubbard and Hunten also analyzed a Pluto light curve obtained in Tasmania by Dieters, Hill, and Watson. It indicated a remarkably extended atmosphere with a surface pressure of a few microbars.

c. Writing up (A. [Tyler] Sprague) of the accumulated data on Mercurian sodium, seeking evidence of spatial and temporal variations with due account for seeing quality. Publication of her work on grain-boundary diffusion in the Moon and Mercury.

Further observations of lunar sodium, mainly in connection with other observations.

Completion of the analysis of the existing data on Venus aurora and lightning, and Mars water vapor (B. Rizk). Possible survey of Venus water vapor.

Occultations will be observed as opportunities arise.

d. Observations of sodium in the the tenuous lunar atmosphere. A.L. Tyler, R.W.H. Kozlowski, and D.M. Hunten, Geophys. Res. Lett. 15, 1141-44 (1988). Occultation evidence for an atmosphere on Pluto. W.B. Hubbard et al., Nature 336, 452-4 (1988).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Radiative Transfer in Planetary Atmospheres

PERFORMING ORGANIZATION

Department of Physics and Astronomy
University of Massachusetts
Amherst, MA 01003

INVESTIGATOR'S NAME

William M. Irvine

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Theoretical techniques and observations at millimeter wavelengths are combined to study the atmospheres of planets and comets, planetary and satellite regoliths, and planetary rings.

b. Theoretical study of the reflection of light by planetary and satellite regoliths continued, including both calculation of the phase function of individual particles and analysis of multiple scattering and mutual shadowing among the surface particles. The former included both the study of rough particles modeled as stochastically deformed spheres and of randomly oriented crystals. The surface layer is treated by taking the surface heights to be stochastically distributed according to a multi-variate normal distribution. The parameters of the theory are in principle measurable in the laboratory. Analysis continued of the very high quality data on the 18cm OH line observed in recent comets. The high spectral resolution and high signal-to-noise make these lines ideal for study of the kinematics in cometary comae. Modeling is likewise continuing for the line profiles observed in the lowest rotational transition of HCN in Comet Halley in order to better estimate the excitation and hence the abundance of HCN, as well as the kinematics of parent molecules in the coma. A collaborative program to combine data from the FCRAO 14m antenna with interferometric data obtained at the Hat Creek Radio Observatory is allowing aperture synthesis mapping of Venus in the CO J=1-0 line.

c. The study of radiative transfer in planetary and satellite regoliths and cometary nuclei will be continued, with particular reference to analyzing data obtained on the USSR Phobos mission. Modeling of the OH line profiles and production rate for Comets Halley, Giacobini-Zinner, Thiele, Hartley-Good, and Wilson will continue. Study of the thermodynamics and excitation of HCN in the coma of Comet Halley will also continue. The question of whether cometary HCN is a parent molecule or originates in a distributed source in the coma is being investigated. Multiple frequency carbon monoxide observations for Venus and Mars will take place, and analysis will be carried out for the aperture synthesis observations of Venus.

d. During the past year 3 articles have been published in scientific journals or conference proceedings (see attached list) and another three have appeared as abstracts.

Bibliography

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Schloerb, F.P., "Collisional Quenching of Cometary Emission in the 18cm OH Transitions", Astrophys. J., 332, 524 (1988).

Swade, D.A. and Schloerb, F.P. (1988), "A Source Model for the Molecular Core of L134N", in Molecular Clouds in the Milky Way and External Galaxies, eds. Dickman Snell, Young (Berlin: Springer-Verlag), pp. 170-171.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE HIGH RESOLUTION INFRARED PLANETARY ASTRONOMY USING CRYOGENIC
GRATING SPECTROMETERS

PERFORMING ORGANIZATION

Performing Organization: Planetary Systems Branch, Code 693, NASA
Goddard Space Flight Center

INVESTIGATOR'S NAME

Donald E. Jennings

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

Our purpose in this program is to observe the infrared spectra of planets and comets at the highest possible spectral resolution and sensitivity. Molecular lines formed in planetary atmospheres are narrow, requiring resolving powers near 10^5 to completely resolve lineshapes and rotational structure. Resolution and sensitivity are required in ground-based studies of atmospheric composition, chemistry and dynamics because weaker, obscured lines are often the most important. Moreover, high spatial resolution is generally needed to map a planet, and this in turn requires high sensitivity. Our primary goal is to follow up results from Voyager, Viking, and other missions, and to prepare a basis for future missions. Accomplishments in this program include 0.01 cm^{-1} spectroscopy of Jupiter, Mars and Venus with our cryogenic grating postdisperser attached to the FTS's at the Kitt Peak McMath and 4-meter telescopes. Ethane and acetylene were observed in Jupiter at 12 to 14 micron, and deuterated water was observed on Mars at 3.7 microns. In addition, we imaged the equatorial region of Jupiter at 8-12 microns to search for thermal structure and oscillations.

Publications

1. "A search for p-mode oscillations of Jupiter: serendipitous observations of non-acoustic thermal wave structure," D. Deming, M. Mumma, F. Espenak, D. Jennings, T. Kostiuik, G. Wiedemann, R. Loewenstein, and J. Piscitelli, *Astrophys. J.*, in press (1989).
2. "Postdispersion system for astronomical observations with Fourier transform spectrometers in the thermal IR," G. R. Wiedemann, D. E. Jennings, R. A. Hanel, V. G. Kunde, S. H. Moseley, G. Lamb, M. D. Petroff and M. G. Stapelbroek, *Applied Optics* 28, 139 (1989).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Temporal Monitoring of Active Comets

PERFORMING ORGANIZATION

Institute for Astronomy / University of Hawaii
2680 Woodlawn Drive
Honolulu
HI 96822

INVESTIGATOR'S NAME

David Jewitt

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

(a). **Strategy:**

We are using temporal variations in active comets as a tool with which to probe the physics of the inner coma, and of mass loss at the cometary surface. Although it is widely recognized that comets are variable bodies, relatively little systematic work has been done to quantitatively define the nature of the variability. We use time - resolved CCD spectra, and CCD images to study activity in comets at a range of heliocentric distances. Specific questions which we aim to address using the new data include

- (i). what are the timescales for variation in cometary comae and what determines these timescales?
- (ii). what is the effect of nucleus rotation on the coma morphology (equivalently, what can be learned about the nucleus from observations of the coma)?
- (iii). what are the statistics of "outbursts" and how do outbursts fit into the model of sublimation from a mantled nucleus?
- (iv). how do temporal variations in the mass loss rate affect the spatial distribution of species in the coma? Can coma waves be detected?

(b). **Accomplishments:**

(i). We have detected a "quiescent coma" in comet P/Schwassmann - Wachmann 1 at $R \sim 6$ AU. This coma is present at all times in 1987 - 1988, and represents a mode of activity physically distinct from the more famous outbursts of this comet. The nucleus loses about 100 kg / s in the quiescent coma. Surprisingly, equilibrium sublimation of crystalline water ice may be sufficient to produce the continuous coma. Possible connections between the quiescent coma and the sporadic outbursts are being explored

(ii). The interaction between the nucleus of P/Tempel 2 (rotation period 8.95 hrs) and the near - nucleus coma is surprisingly simple. The coma shows no evidence of periodic modulation by the nucleus, in contrast to the modulations observed in P/Halley. A simple model has been developed to account for this qualitatively different behavior.

(iii). In common with the coma of Tempel 2, (but contrary to our expectations) we find that the comae of a majority of comets, when studied in detail, exhibit remarkable photometric stability. We are attempting to understand this stability using a time - dependent Monte Carlo model of the coma which includes a broad distribution of particle sizes.

(c). **Future Work:**

The time - series photometry will continue at the Mauna Kea Observatory, where the excellence of the site will permit observations at twice the spatial resolution yet attained. A large number of time - resolved measurements will be needed to obtain a representative view of the nature of the temporal variations in comets, and so to address the above mentioned questions.

Publications of David Jewitt

- J. X. Luu and D. C. Jewitt (1988), "A Two Part Search for Slow Moving Objects", *Astronomical Journal*, **95**, 1256 - 1262.
- D. C. Jewitt and K. J. Meech (1988), "Absence of a Color - Distance Trend in Comets", *Astronomical Journal*, **96**, 1723 - 1730.
- J. J. Klavetter (1989), "Rotation of Hyperion. I. Observations", *Astronomical Journal*, **97**, 570 - 579.
- D. C. Jewitt and J. X. Luu (1988), "A CCD Portrait of Comet P/Tempel 2", *Astronomical Journal*, in press.
- J. X. Luu and D. C. Jewitt (1989), "On the Ratio of C - Types to S - Types Among the Near Earth Asteroids", *Astronomical Journal*, submitted.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

INFRARED OBSERVATIONS OF OUTER PLANET SATELLITES

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91109

INVESTIGATOR'S NAME

Johnson, T.V.

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

A. **OBJECTIVE:** This task supports IR observations of the outer planet satellites. These data provide vital information about the thermophysical properties of satellite surfaces, including internal heat sources for Io. Observations include both broad and narrow band measurements in the 2 to 20 μm spectral range. Most observations are carried out at the IRTF facility on Mauna Kea. Types of observation and target priority are determined to make maximum use of existing data from Voyager and other missions, support on-going and planned missions such as Galileo, and to develop techniques and data for planning new missions and instrumentation.

B. **PROGRESS:** The program in the last year has aimed at obtaining longitude coverage on Io to establish stability of hot spot patterns previously reported. Several runs produced the most complete data set for an apparition since we started the program in 1983; unfortunately bad weather limited coverage of key longitude ranges containing the largest known hot spot Loki. Among the preliminary results is the observation of an outburst in Io's thermal flux that was measured at 4.8, 8.7 and 20 μm . Analysis of those data has given the best evidence to date of silicate volcanism on Io; this is one of the most significant pieces of the puzzle as to the relative roles of silicate and sulfur volcanism on Io. We are collaborating with J. Goguen (JPL) to finish reduction of mutual event data, which have already improved ephemeris information for the satellites. The data appear to place significant limits on the characteristics of any leading side hot spots. Our earlier data were used in two published analysis papers concerning correlations of hot and dark regions and models for the occultation data at several wavelengths.

C. **PROPOSED WORK:** During 1989 we plan a series of 3 to 4 observing sessions. Emphasis will be on further study of high temperature eruptive events on Io, on studying the suspected variability of the high temperature component(s) suggested by last year's data and on obtaining longitude coverage constraining the hot spots in the Loki region.

REFERENCES

Johnson, T.V. et al., Io: Evidence of silicate volcanism in 1986.

Goguen, J.D., et al., Io hot spots: IR photometry of satellite occultations.

Goguen, J.D., et al., Io hot spots: Satellite occultations of sources.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Goldstone Solar System Radar

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

Jurgens, R.F.

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

A. Objectives: (1) Planning, direction, experiment design, and coordination of data acquisition and engineering activities in support of all Goldstone planetary radar astronomy. (2) Support radar data-processing facilities, currently being used for virtually all Goldstone data reduction: a VAX 11/780 computer system, an FPS 5210 array processor, terminals, tape drives, and image-display devices, as well as the large body of data-reduction software to accommodate the variety of data-acquisition formats and stratagems.

B. Progress: Since the completion of the 70m antenna upgrade in June, the GSSR has supported 93 tracks and acquired new data for Mercury, Venus, Mars, Phobos, Deimos, Ganymede, Callisto, Europa, Io, Saturn's rings and asteroid 1980PA. Many of these observations were made using the new dual-polarization receiving system, the high resolution ranging system or the wide band digital spectrum analyzer at DSS-13. Four of the tracks used the Goldstone/VLA bistatic mode to make images of Saturn's rings and the Martian surface. The major objectives of all experiments were met. New data verification software has been developed for each new data type. Data analysis is continuing for each of the experiments, and preliminary results have been reported in LPSC and BAAS abstracts and in journal articles.

C. Proposed Work: Observations of Titan will be made in June using the Goldstone/VLA configuration in hope of detecting this elusive object. The Goldstone/VLA configuration is a factor of four more sensitive than the monostatic system used for the last attempt, and only the ethane ocean model could escape detection. Observation of Mercury for general relativity and topography, and the asteroids Betulia, and Cujo follow this FY. Planning for the observations of Venus beginning in November of 89 are currently underway. These observations are aimed at extending the equatorial coverage as far east and west of current coverage as possible and providing the last high resolution overlapping coverage for improving the spin axis definition. Three new image display devices are being implemented using networking to existing PC clones and a MAC to allow several users to edit imaging data simultaneously.

D. Summary Bibliography:

Clark, P.E., Leake, M.S., and Jurgens, R.F. (1988), "Goldstone Radar Observations of Mercury," In Mercury (C.R. Chapman and F. Vilas, eds.), Univ. of Arizona Press, 77-100.

Jurgens, R.F., Slade, M.A., Robinett, L., Brokl, S., Downs, G.S., Franck, C., Morris, G.A., Farazian, K.H. and Chan, F.P. (1988), "High-Resolution Images of Venus from Ground-Based Radar", Geophys. Res. Letter, 65, 577-580.

Jurgens, R.F., Slade, M.A., and Saunders, R.S. (1988) "Evidence for Highly Reflecting Materials on the Surface of Venus", Science, 240, 1021-1023.

Ostro, S.J., Yeomans, D.K., Chodas, P.W., Jurgens, R.F., Goldstein, R.M., and Thompson, T.W. (1989) " Radar Observations of Asteroid 1986 JK, Icarus, 78, (in press).

Roth, L.E., Saunders, R.S., Downs, G.S., and Schubert, G. (1989) "Radar Altimetry of Large Martian Craters", Icarus, (in press).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

PLANETARY MICROWAVE AND SUBMILLIMETER ASTRONOMY

PERFORMING ORGANIZATION

JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CA 91109

INVESTIGATOR'S NAME

Michael J. Klein

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. STRATEGY: Develop a comprehensive observational and analytical program to study solar system physics and meteorology by measuring the radio emission of the planets from microwave to submillimeter wavelengths. A primary objective is to conduct spectroscopic and continuum observations with the new JPL and Caltech submillimeter receivers at the Caltech Submillimeter Observatory (CSO) on Mauna Kea, Hawaii. A secondary objective is to continue to monitor the time variable planetary phenomena (e.g. Jupiter and Uranus) at centimeter wavelengths using the NASA antennas of the Deep Space Network (DSN).

b. ACCOMPLISHMENTS: We published a paper reporting our work on the correlation studies between Solar wind parameters and the decimetric radio emission from Jupiter. We increased the temporal coverage and the precision of the NASA-JPL Jupiter Patrol observations in response to the Program for Studying Temporal Variations in the Jovian System, prepared by the International Jupiter Watch (IJW, Aug 1988). Recent measurements from the DSN 70-m antenna in Spain indicate that the precision of the ongoing program to monitor the 8 GHz brightness temperature of Uranus will be improved by nearly a factor of two as a result of the antenna upgrade. We completed a paper (with Dr. Paul Steffes, Georgia Tech) reporting new observations of the microwave emission of Venus from 1.3 to 3.6 cm, and comparing the results with laboratory measurements of H_2SO_4 . Work has begun to develop an improved model of the Venus microwave emission spectrum. The model will incorporate the results of our theoretical study to interpret the laboratory measurements of the microwave absorption of H_2SO_4 published by Steffes (Ap. J. 1986).

c. ANTICIPATED ACCOMPLISHMENTS: We plan to: (1) continue our study of the microwave opacity of H_2SO_4 and its impact on the emission spectrum of Venus; (2) carry out a new study of the microwave spectrum of Jupiter's synchrotron emission and collaborate with UC Berkeley to search for short term variations with timescales of days to weeks; (3) conduct measurements of planets at 22 GHz (1.35 cm) and 32 GHz (0.8 cm) using the newly upgraded DSN 70-m antennas. We will begin system evaluation and calibration measurements of the 600 GHz (0.5 mm) receiver at CSO as soon as it is installed on the telescope; according to the current schedule, installation should occur late in 1990.

d. PUBLICATIONS:

Bolton, S.J., Gulkis, S., Klein, M.J., de Pater, I., and Thompson, T. J.: "Correlation Studies Between Solar Wind Parameters and the Decimetric Radio Emission from Jupiter", J. Geophys Res 94, 121-128, January (1989).

de Pater, I and Klein, M.J.: "Time Variability in Jupiter's Synchrotron Radiation," Review Paper in Proc. of Workshop on Time Variable Phenomena in Jovian System (Flagstaff, AZ), In Press, 1989.

Klein, M.J., Thompson, T.J., and Bolton, S.J., "Systematic Observation and Correlation Studies of Variations in the Synchrotron Emission from Jupiter, " Proceedings of Workshop on Time Variable Phenomena in the Jovian System (Flagstaff, AZ), In Press, 1989.

Steffes, P.G., Klein, M. J. and Jenkins, J. M., "Observations of the Microwave Emission of Venus from 1.3 to 3.6 cm," Submitted to Icarus, (Jan 1989).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

SOLAR SYSTEM OCCULTATION SURVEYS

PERFORMING ORGANIZATION

Lick Observatory University of California Santa Cruz, CA 95060

INVESTIGATOR'S NAME

Arnold R. Klemola

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

STRATEGY: Direct photographs obtained with the Lick 51-cm astrograph are scanned along the trajectories of the outer planets Uranus, Neptune, and Pluto in order to identify candidate stars for possible occultations over the period 1990 to 2000. Precise equatorial coordinates measured for these candidate stars are then used to compute preliminary elements for the occultations, suitable for planning by observers at other institutes interested in observing these occultations for studies of these planets (including atmospheres and rings), and their satellites. This program is carried out with Dr. Douglas Mink (SAO), who is responsible for the computations of the occultation elements, using the Lick star measures as input.

PROGRESS (PREVIOUS YEAR): Since this work started only two weeks ago, only some very early steps can be reported. This includes selection of plates centers for observations at the telescope and the partial preparation of planetary ephemerides in computer-accessible form, needed later for the plate survey.

ACCOMPLISHMENTS THIS YEAR: Photography with the Lick astrograph will be made late spring and early summer for the fields along the trajectories of the three planets. Visual surveys, using the Lick Gaertner Survey and Coordinate Measuring System will follow thereafter, to isolate several thousand stars lying in a band to include the full range of satellite motions, permitting satellite occultation events to be found also. Approximate yellow magnitudes will also be determined for the stars. Later in the year these candidate stars (on magnetic tape) will be transmitted to Dr. Mink (SAO) for his contribution, namely, the computation of the occultation elements for the surviving stars among the candidates in the wide bands.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Infrared Spectroscopy of Jupiter and Saturn

PERFORMING ORGANIZATION

Astronomy Program
State University of New York at Stony Brook

INVESTIGATOR'S NAME

Roger Knacke, Principal Investigator

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy: High resolution infrared spectroscopy provides unique insights into the chemistry and dynamics of the atmospheres of Jupiter and Saturn. The 5 μm spectral region, which is transparent to deep levels, is particularly useful for the identification of molecules that are present at very low (parts per billion) concentrations. These are tracers of convective and strongly non-equilibrium processes in the atmospheres. High resolution ground-based spectroscopy complements Voyager and Galileo measurements. Spectroscopy is sensitive to lower mixing ratios for selected molecules, while the on-board mass spectrometers probe molecules that are spectroscopically inaccessible.

b. Accomplishments: The search for the molecule, AsH_3 , arsine, that we proposed last year was successfully concluded with the discovery of this molecule in Saturn and Jupiter. A prominent absorption feature in both planets near 4.7 μm coincides with the ν_2 Q branch of AsH_3 . A smaller absorption at the location of the ν_1 Q branch of AsH_3 is also observed in Saturn. Arsenic is only the eighth element detected in the atmospheres of the giant planets. The mole fractions of AsH_3 are $q\text{AsH}_3 = 1.8 \pm 1.8$ ppb in Saturn and $q\text{AsH}_3 = 0.7 \pm 0.7$ ppb in Jupiter, and are probably representative of the As/H ratio in the gaseous envelopes. Arsenic is significantly enriched over the solar abundance in both planets. The ratio of the abundances, which can be computed without making absolute abundance determinations, suggests that AsH_3 is almost a factor of two higher in Saturn than in Jupiter. The enrichments are consistent with the core instability model for the formation of the giant planets. Models of arsenic chemistry that predict strong depletions of AsH_3 at temperatures below 370 K are not consistent with the observations, suggesting that vertical convection or perhaps some other mechanism inhibits depletion.

c. Anticipated Accomplishments: High resolution spectra of CO in Saturn are being analyzed. Recent laboratory data of PH_3 make possible much more precise synthetic spectral models, thus opening new opportunities for the investigation of giant planet atmospheres. We propose to observe 5 μm spectra of both Jupiter and Saturn to continue our search for new molecules. Observations are planned to improve the AsH_3 abundance determinations in both planets and to study latitude variations of GeH_4 , PH_3 , and CO in Jupiter. We plan to obtain moderate resolution spectra of Uranus and Neptune near 5 μm using recently developed infrared array spectrometers.

d. Publications

Noll, K.S., Geballe, T.R., and Knacke, R.F. 1989, Arsine in Saturn and Jupiter, Ap. J. (Letters), in press.

Noll, K.S., Knacke, R.F., Geballe, T.R., Tokunaga, A.T. 1988, Evidence for Germane in Saturn, Icarus, 75, 409-422.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION RESEARCH AND TECHNOLOGY RESUME	
TITLE	Advanced Infrared Astronomy
PERFORMING ORGANIZATION	Planetary Systems Branch Laboratory for Extraterrestrial Physics Goddard Space Flight Center Greenbelt MD 20771
INVESTIGATOR'S NAME	T. Kostiuk / D. Deming / M. Mumma
DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)	
<p>a. <u>Strategy</u>: This task supports the application of infrared heterodyne and Fourier transform spectroscopy to ultra-high resolution studies of molecular constituents of planetary atmospheres and cometary comae. High spectral and spatial resolution measurement and analysis of individual spectral lines permits the retrieval of atmospheric molecular abundances and temperatures and thus, information on local photochemical processes. Determination of absolute line positions to better than 10^{-8} permits direct measurement of gas velocities to a few m/sec. Observations are made from ground based heterodyne spectrometers at the NSO McMath solar telescope at Kitt Peak and from the NASA Infrared Telescope Facility on Mauna Kea, Hawaii. FTS observations are conducted from ground based facilities and the Kuiper Airborne Observatory.</p> <p>b. <u>Accomplishments</u>: Data on subsolar to antisolar circulation at 110 km altitude on Venus, retrieved from measurements of $10\mu\text{m}$ non-thermal CO_2 emission lines, were used to constrain 2-D dynamical models. Similar measurements were made on Mars, and data are being analyzed to search for mesospheric meridional and zonal flow. Distribution of ozone on Mars was measured and analysis is in progress. Initial results indicate O_3 abundances $\sim 10 \times$ lower than Mariner 9 results. Measurements of C_2H_6 emission lines near the N pole of Jupiter revealed a two-fold enhancement over an extended longitudinal region. This result is in contrast to a small localized hot spot observed in CH_4 and C_2H_2 and, if due to increased temperature ($\sim 10\text{K}$), implies dynamical activity in the stratosphere. Non-acoustic thermal wave structure was observed in the $8\text{-}13\mu\text{m}$ band (both at 20°N and the equator) on Jupiter. This low frequency wave may be related to fluid dynamical activity beneath the surface meteorology. Water and HDO absorption lines near $2.65\mu\text{m}$ were measured on Mars using the FTS on the Kuiper Airborne Observatory. An H_2O column abundance of $9.9 \text{ pr } \mu\text{m}$ and a D/H ratio 5.15 ± 0.2 times the terrestrial value were obtained. Development of excitation and scattering models for comets is continuing and results have been applied to H_2O on comets Halley and Wilson and to the verification of the presence and variability of formaldehyde in Halley.</p> <p>c. <u>Anticipated accomplishments</u>: IR heterodyne observations of C_2H_6 on Neptune will be made to determine the mole fraction, thus constraining the photochemical models and providing ground based data for interpretation of Voyager results. Spatial distribution of C_2H_4 on Jupiter will be obtained and the behavior of hydrocarbons near Jovian polar regions studied. Implication for photochemistry and stratospheric dynamics will be evaluated. Mesospheric wind data on Mars will be analyzed and compared to dynamical models. Analysis of Martian ozone distribution data will continue and implications for atmospheric chemistry and evolution studied. Measurements of D/H on Venus and H_2O on comet Brorsen-Metcalf will be made from the KAO. Hydrocarbon emission on Saturn will be studied using line spectra measurements and spectral imaging.</p>	

d. Publications:

- 1989 "Is ethane varying in the Jovian north polar "hot spot"?", T. Kostiuk, F. Espenak, and M. J. Mumma, Proc. Intl. Conf. Time Variable Phenomena in the Jovian System, NASA Conf. Pub. (ed. M. Belton) (in press).
- 1989 "Infrared studies of hydrocarbons on Jupiter", T. Kostiuk, F. Espenak, M. J. Mumma and P. Romani, Infrared Physics, (in press).
- 1989 "A search for P-mode oscillations of Jupiter: Serendipitous observations of non-acoustic thermal wave structure", D. Deming, M. J. Mumma, F. Espenak, D. E. Jennings, T. Kostiuk, G. Wiedemann, R. Lowenstein, and J. Piscitelli, Ap. J. (in press).
- 1989 "Probing our solar system at infrared wavelengths", M. J. Mumma, Infrared Physics (in press).
- 1989 "The value of D/H in the Martian atmosphere: Measurement of HDO and H₂O using the Kuiper Airborne Observatory", G. L. Bjoraker, M. J. Mumma, and H. P. Larson, Proc. 4th Intl. Conf. on Mars, 10-13, January 1989, Tucson, AZ, p.69.
- 1988 "Airborne infrared spectroscopy of Comet Wilson 1986 and comparisons with Comet Halley", H. P. Larson, H. A. Weaver, M. J. Mumma, and S. Drapatz, Ap. J. (in press).
- 1989 "Possible identification of the 3.4 μ m emission feature in comets", A. C. Danks, D. L. Lambert, and M. J. Mumma, Proc. Cornell Cometary Grain Workshop (in press).
- 1989 "Infrared fluorescence efficiencies for the ν_1 and ν_5 bands of formaldehyde in the solar radiation field", D. G. Reuter, M. J. Mumma and S. Nadler, Ap. J. (in press).
- 1989 "On the identification of formaldehyde (H₂CO) in Halley's comet", M. J. Mumma and D. Reuter, Ap. J. (in press).
- 1989 "The heliocentric evolution of cometary infrared spectra: Results from an organic grain model", C. F. Chyba, C. Sagan, and M. J. Mumma, Icarus (in press).
- 1988 "Measurement of the ortho-para ratio and nuclear spin temperature of water vapor in comets Halley and Wilson (1986s) and implications for their origin and evolution", M. J. Mumma, W. E. Blass, H. A. Weaver, and H. P. Larson, Proc. STSI Workshop on the Origin and Evolution of Planetary Systems (March, 1988).
- 1988 "Observations of hydrated minerals in comets and a possible link to interstellar grains", H. A. Weaver, M. J. Mumma, H. P. Larson, and S. Drapatz, Proc. STSI Workshop on the Origin and Evolution of Planetary Systems (March, 1988).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

COMETARY SPECTROSCOPY AND IMAGING

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Stephen M. Larson

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy: This is an ongoing observational program to investigate the spectroscopic and morphological characteristics of comets (and other primitive bodies) over a wide range of heliocentric distances as they may suggest or constrain models of cometary formation environments and evolution. Direct images of all observable comets ($M_2 < 21$) and spectra of the brighter ones are obtained on a monthly basis (weather permitting) with a novel CCD spectrograph/camera. Scale lengths of the principal emissions of OH, NH, CN, C₃, C₂, NH₂, OI, and abundance of dust and ions in different comets can be compared. The direct images are used for astrometry and studies of dust anisotropy which can provide information on the spin vector and gross surface morphology.

b. Accomplishments: This past year we reduced and submitted over 800 images of P/Halley to the IHW Halley archive. CCD photometry of P/Halley confirmed the 7.4 day activity variations reported by Millis and Schleicher, and the enhanced images show that the jet morphology also repeats in a 7.4 day cycle over at least 5 cycles in March and April 1986. However, the measured outflow velocity and curvature of the jets are more consistent with a 2.2 day rotation period for the nucleus. Given the shape of the nucleus from spacecraft data, the nodding motion of an asymmetric top appears to be consistent with the observed orientation. Direct CCD images (and sometimes spectra) were obtained of Comets Borrelly (1987p), Bradfield (1987s), Comas-Sola (1986j), Ge-Wang (1988o), Gunn, Halley (1986III), Hartley 3 (1988d), Helin-Roman-Crockett (1989b), Kohoutek (1986k), Levy (1987y), Levy (1988e), Liller (1988a), Longmore (1987c1), Maury-Phinney (1988c), McNaught (1987b1), Reinmuth 1 (1987r), Schwassmann-Wachmann 1, Schwassmann-Wachmann 2 (1986h), Shoemaker (1987o), Shoemaker (1988b), Shoemaker-Holt (1988g), Tempel 2 (1987g), West-Kohoutek-Ikemura (1987x), Wilson (1987VII), Yanaka (1988r) and Yanaka (1989a). We observed the split nucleus of Comet Wilson (IAUC 4555) enabling Z. Sekanina (JPL) to determine the time of splitting (IAUC 4722). With S. Bus (Lowell Obs.) and E. Bus we made astrometric measurements of comets Levy (1988e) and Shoemaker-Holt (1988g) enabling B. Marsden (CFA) to determine that they are fragments of the same comet which split during its last perihelion passage some 10^3 years ago. We monitored the fading of the coma of P/Halley beyond 9 AU. Several minor planets were also observed including 2060 Chiron which did not show any coma brighter than about magnitude 24 even though it was showing anomalous brightening. E. Bus carried out photometry of Veried with our CCD and found a much smaller lightcurve amplitude than reported by others. With F. Vilas (JSC), coronagraphic 340-890nm CCD spectra of Phobos and Deimos were obtained over several elongations during the favorable Mars apparition. Preliminary reduction shows that the two satellites have the same reflectance spectra which are consistent with carbonaceous chondritic material. Possible slight differences between leading and following hemispheres are being investigated. Very high spatial resolution CCD images of Mars were obtained that show albedo features as small as 100 km.

c. Anticipated accomplishments: We will continue the monthly CCD imaging, spectral, and astrometric observations of comets and asteroids with emphasis on mission target objects and P/Brorsen-Metcalf which with a similar period but lower inclination, will be interesting to compare with P/Halley.

d. Summary bibliography:

Larson, S. (1988) Gas and dust jets in a spin. NATURE, 332, No. 6166, 681-682.

Sagdeev, R.Z., Szego K., Smith, B.A., Larson, S., Merenyi, E.,
Kondor, A. and Toth, I. (1989) The Rotation of Comet Halley.
ASTRON J., 546-551.

Abstracts and IAU Circulars are not included.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Infrared Observations of Solar System Objects

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Larry A. Lebofsky

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

- a) This program is a continuing effort to study the near (reflected) to thermal infrared flux from asteroids and other airless bodies using groundbased telescopes. The goal of the observations is to investigate the mineralogy and thermophysical properties of these bodies and to support present and potential future missions such as Galileo, CRAF, IRAS, and SIRTf.
- b) During the past year, we have been working on four major projects: 1) structures of water of hydration on asteroids, 2) thermal IR spectroscopy of Mercury for mineral identification, 3) continued observations of planets mutual events and 4) thermal IR observations (10 to 1100 μm) of bright asteroids for comparison with IRAS observations and improvement of thermal models.
- c) Much of our effort in the coming year will be on the study of the mineralogy of asteroids, in particular, the distribution of water of hydration on asteroids as a function of class and heliocentric distance. Our high resolution observations of brighter asteroids along with lower resolution observations outer belt and Trojan asteroids is greatly increasing our understanding of the distribution of water in the asteroids and how water was originally incorporated in them.
- d) Lebofsky 1989, Lebofsky et al. 1988, Lebofsky et al. 1989, Lebofsky and Spencer 1989, Spencer, Lebofsky and Sykes 1989, and Tyler et al. 1988.

REFERENCES

- LEBOFSKY, L. A. 1989. Wavelength dependence of IRAS asteroid diameters and albedos. *Icarus* (in press).
- LEBOFSKY, L. A., R. GREENBERG, E. F. TEDESCO, AND G. J. VEEDER 1988. Infrared lightcurves of asteroids 532 Herculina and 45 Eugenia: proof of the absence of significant albedo markings. *Icarus* **75**, 518-526.
- LEBOFSKY, L. A., T. D. JONES, P. D. OWENBY, M. A. FEIERBERG, AND G. J. CONSOLMAGNO 1989. The nature of low albedo asteroids from 3-spectroscopy. *Icarus* (submitted).
- LEBOFSKY, L. A., AND J. R. SPENCER 1989. Radiometry and thermal modeling of asteroids. *Asteroids II*, (R. Binzel and T. Gehrels, Ed.), in press.
- SPENCER, J. R., L. A. LEBOFSKY, AND M. V. SYKES 1989. Systematic biases in radiometric diameter determinations. *Icarus* (in press).
- TYLER, A. L., R. W. M. KOZLOWSKI, AND L. A. LEBOFSKY 1988. Determination of rocktype on Mercury and the Moon through remote sensing in the thermal infrared. *Geophys. Res. Lett.* **15**, 808-811.
- VEEDER, G. J., M. HANNER, D. L. MATSON, E. F. TEDESCO, L. A. LEBOFSKY, AND A. T. TOKUNAGA 1989. Radiometry of near earth asteroids, *Astron. Jour.*, (in press).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Outer Planet Studies
NASA Grant NSG-7499 (NAGW-1505)

PERFORMING ORGANIZATION

Lowell Observatory
1400 West Mars Hill Road
Flagstaff, AZ 86001

INVESTIGATOR'S NAME

Barry L. Lutz

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a) **Strategy.** The research supported by this grant focuses on observational studies of the composition, structure and variability of planetary, satellite and cometary atmospheres, and the investigation of the problems associated with the fundamental calibration of these data. In addition to carrying out basic research into the origin, evolution and current state of the solar system, these studies provide "ground-truth" support for observations of the solar system by NASA's missions, including the *Voyager* and *Galileo* spacecraft, the *Hubble Space Telescope*, and the proposed *CRAF-Cassini* mission. A very modest laboratory effort is also maintained to provide essential data needed by these observational programs, which may be otherwise unavailable.

b) **Accomplishments in 1988.** Major accomplishments during the past year include: (1) Completion of our analysis of HDO in the spectrum of Mars, determination of the D/H ratio in its atmosphere and publication of the results in *Science*; (2) Completion and publication in *The Astrophysical Journal* of our study of CH₃D in the spectrum of Titan and a determination of the mixing ratio in its atmosphere; (3) Completion of our analysis of CH₃D in the spectrum of Neptune and a determination of the CH₃D/CH₄ mixing ratio in its atmosphere; (4) Continuation of our long-base line time series of spatially-resolved, spectrophotometric observations of the belts and zones of Jupiter.

c) **Anticipated Accomplishments in 1989.** Major efforts proposed for the next year include: (1) Publication of our study of CH₃D in the spectrum of Neptune and its implied atmospheric CH₃D/CH₄ ratio; (2) Search for HDO in the atmosphere of Venus as part of our investigation of the distribution of deuterium in the solar system and its relationship to the origin and evolution of the planets; (3) Completion of time series of spectrophotometric observations of Neptune and a determination of its geometric and Bond albedos as part of our study of temporal variability of its atmosphere, in support of the 1989 *Voyager* encounter; (4) Publication of the recalibration of the Sun against Vega and continuation of our study of the fundamental calibration problems associated with solar analogs, needed to accurately determine planetary albedos on a common photometric scale; (5) Continuation of our time series of spatially resolved spectrophotometric observations of the Jovian belts and zones to characterize the spatial and temporal variations of the Jovian atmospheric structure in support of the *Galileo* mission; (6) Recording of new spectrophotometric observations of selected, target-of-opportunity comets in support of the cometary program goals of the *CRAF-Cassini* mission.

d) Papers Published, In Press or Submitted in 1988.

- "Monodeuterated Methane in the Outer Solar System. II. Its Abundance on Titan" (C. de Bergh, B. L. Lutz, T. Owen, and J. Chauville), *Astrophys. J.* **329**, 951 (1988).
- "Deuterium on Mars: The Abundance of HDO and the Value of D/H" (T. Owen, J.-P. Maillard, C. de Bergh, and B. L. Lutz), *Science* **240**, 1767 (1988).
- "Spatial and Temporal Variations in the Atmosphere of Jupiter: Polarimetric and Photometric Constraints" (B. E. Carlson and B. L. Lutz), in *Proceedings of the International Workshop on Time-Variable Phenomena in the Jovian System* (M. J. Belton and R. A. West, eds.). NASA Special Publication, in press.
- "International Jupiter Watch; A Program to Study the Time Variability of the Jovian System" (C. T. Russell, J. J. Caldwell, I. de Pater, J. Gougen, M. J. Klein, B. L. Lutz, N. M. Schneider, W. M. Sinton, and R. A. West), in press.
- "Measurements of the D/H Ratio in Planetary Atmospheres by Ground-Based Infrared Spectroscopy" (C. de Bergh, B. L. Lutz, T. Owen and J. P. Maillard), in *Proceedings of the Salamanca Conference on Infrared Spectroscopy*, in press.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE Photopolarimetric Imaging of the Giant Planets
NASA Grant NAGW-1374

PERFORMING ORGANIZATION
Lowell Observatory
1400 West Mars Hill Road
Flagstaff, AZ 86001

INVESTIGATOR'S NAME
Barry L. Lutz

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a) **Strategy.** The research grant supports the recording of new, synoptic, high signal-to-noise, spectrally resolved, photometric and polarimetric CCD images of Jupiter in narrow spectral bands. The photopolarimetric observations are designed to characterize the vertical structure of the Jovian atmosphere, and put constraints on the nature and distribution of the aerosols in it through detailed study of the photometric and polarizing properties of belts and zones in methane absorptions and in continuum bandpasses. We expect to continue the coverage for a time period sufficient to look for and study long-term temporal variations in it. These images will form a homogeneous set of ground-based data, including observations contemporaneous with the *Galileo* mission which are required for the interpretation of the spacecraft data. They also provide the link that serves to tie the "snapshot" of Jupiter obtained during the encounter to more temporally extended studies of the long-term variations of the atmosphere, and they establish a database for fundamental research on this giant planet.

b) **Accomplishments in 1988** Funding for this proposal began only in January 1989 (six weeks prior to the time of writing this summary); however, photopolarimetric observations of Jupiter in three methane bands and three continuum bandpasses have been recorded at several phase angles during this and preceeding preparatory periods.

c) **Anticipated Accomplishments in 1989.** During the first full year covered by this proposal, we expect to continue to obtain narrowband photometrically calibrated images of Jupiter to extend our polarimetric data set to include a broader range of phase angles and more complete global coverage. We also expect to standardize the preliminary processing and reduction approaches that are needed to make homogeneous set of observations from numerous apparitions, and to develop any secondary processing procedures that may be required for model analyses of the data. We also expect to begin the preliminary analysis of a times series of spatially-resolved spectrophotometric observations of the belts and zones of Jupiter obtained in support of the imaging.

d) Papers Published, In Press or Submitted in 1988.

"Spatial and Temporal Variations in the Atmosphere of Jupiter: Polarimetric and Photometric Constraints" (B. E. Carlson and B. L. Lutz), in *Proceedings of the International Workshop on Time-Variable Phenomena in the Jovian System* (M. J. Belton and R. A. West, eds.). NASA Special Publication, in press.

"International Jupiter Watch; A Program to Study the Time Variability of the Jovian System" (C. T. Russell, J. J. Caldwell, I. de Pater, J. Gougen, M. J. Klein, B. L. Lutz, N. M. Schneider, W. M. Sinton, and R. A. West), in press.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

ASTEROID RESEARCH

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

Dennis L. Matson

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

OBJECTIVES: The purpose of this task is to carry out asteroid research in support of NASA's planetary exploration objectives. Original research is carried out on asteroids in order to better characterize asteroids as a whole and measure the properties of individual objects. This information is needed for the planning and design of NASA asteroid flyby and rendezvous missions (e.g. Galileo, CRAF, Cassini).

PROGRESS: [1] Our long ongoing work on asteroid taxonomy has been published. The philosophy behind our three-parameter asteroid taxonomy was to create a relatively simple system, using a minimal number of parameters, sufficient to meet the needs of selecting asteroids for spacecraft flyby. The three parameters we settled upon were IRAS albedo, U-V and v-x color indices. (Effective wavelengths of 0.36, 0.55 and 0.85 microns). Our classification algorithm explicitly accounts for the observational uncertainties in each of the classification parameters, a feature not found in other classifications. Thus, the derived classification in our system depends upon both the parameter values and their uncertainties. Using high quality data we find 11 taxonomic classes. [2] Work on the measurement of asteroidal diameters and albedos continued with the photometry for 22 Aten, Apollo and Amor asteroids presently in press in the Astronomical Journal. [3] We supported the Asteroids II book (University of Arizona Press) by preparing three chapters describing the Asteroid and Comet Survey with the Infrared Astronomical Satellite (IRAS), its results and some of the interpretation of the data. These papers are presently in press. [4] Funding under this task supported Matson's activities as a member of the NASA Planetary Astronomy MOWG and the IRTF MOWG.

PROPOSED WORK: [1] We will continue to give top priority on any near-Earth asteroids which become available for observation. [2] Radiometry for several dozen asteroids will be reduced and submitted for publication. [3] The taxonomic work will be extended to fainter asteroids. [4] This task will continue to support Matson's involvement in NASA MOWGs.

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Papers in press:

Matson, D. L., Asteroids, Comets, Dust: A Post-IRAS Perspective, *Space Research*, (in press).

Matson, D. L., G. J. Veeder, E. F. Tedesco and L. A. Lebofsky, The IRAS Asteroid and Comet Survey, a chapter in *Asteroids II*, R. Binzel, T. Geherels and M. Mathews, eds, University of Arizona Press, Tucson (in press).

Tedesco, E. T., D. L. Matson and G. J. Veeder, Classification of IRAS Asteroids, a chapter in *Asteroids II*, R. Binzel, T. Geherels and M. Mathews, eds, University of Arizona Press, Tucson (in press).

Veeder, G. J., M. S. Hanner, D. L. Matson, E. F. Tedesco, L. A. Lebofsky, and A. T. Tokunaga, Radiometry of Near-Earth Asteroids, *Astronomical Journal* (in press).

Veeder, G. J., E. F. Tedesco and D. L. Matson, Results from the IRAS Asteroid Survey, a chapter in *Asteroids II*, R. Binzel, T. Geherels and M. Mathews, eds, University of Arizona Press, Tucson (in press).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Investigation of Prairie Network Geminid Fireballs

PERFORMING ORGANIZATION

Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge, MA 02138

INVESTIGATOR'S NAME

R. E. McCrosky

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

With the discovery of the minor planet (3200) Phaethon by the IRAS satellite in 1983 and the recognition by Whipple that this body is unquestionably the parent of the Geminid meteor stream, a new window was opened to the understanding of the nature of one or more of the members of the solar system generally thought to be among the most pristine; comets, asteroids, and if they do not belong to either of those two classes, the Apollo asteroids. It is too early to say what Phaethon is. Its only characteristic that relates it to the comets is the meteor shower; otherwise it seems, so far, to be inactive. Other Apollos may also be 'dead' comets. The uniqueness of Phaethon lies in the good luck that permits us to observe the very strong Geminid meteor shower which, judging from the very small dispersion in their orbits, is relatively young. It may well be that Phaethon was an active, meteoroid-producing comet only a few thousand or tens of thousands years ago.

Whatever the true scenario of this object is, the Geminids do offer a possibility to study its nature. It is already known, principally from the work of Jacchia and Whipple, that Geminids differ from most other shower meteors in their lower degree of fragmentation and flaring. Their analysis suggests that Geminids are less fragile and perhaps more dense. We are in the process of a substantial augmentation of existing Geminid data by resurrecting previously unreduced material obtained by the Prairie Network fireball stations during the period 1962-1972. Since the original computers, code, and measuring instruments are extinct, a fresh start was required. At this time, geometrical measurements and orbit determinations are complete for the 50 available meteors. The photometry necessary to proceed with the analysis of the physical characteristics is underway.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Astrometric Observations of Comets and Asteroids and Subsequent Orbital Investigations

PERFORMING ORGANIZATION

Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge MA 02138

INVESTIGATOR'S NAME

Principal Investigator: R. E. McCrosky
Co-investigator: B. G. Marsden

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

(a) Astrometric observations are made of comets and minor planets for use in orbit computations. Direct photographic observations are made with the 1.5-m reflector at the Oak Ridge Observatory. The emphasis is on faint or unusual objects, but attention is also given to newly discovered objects.

(b) During the past year 407 positional measurements were obtained, 77 of them referring to comets. Twelve of the comets were new discoveries, and in most instances our observations were among the first to be obtained; in other cases, also for the predicted returns of short-period comets, our observations were the very last to be secured, thereby giving important extensions to the observed arcs. We also made follow-up astrometry for nine newly-discovered earth-approaching minor planets. Our observations of the earth-approaching object 1982 XB, now numbered (3757), in December 1987 were crucial to the success of the radar-bouncing efforts at Arecibo. We also contributed to the effort in August 1988 likewise on 1980 PA, now numbered (3908), the recovery of which was successful because we caused the arc to be extended from six weeks to five months at the discovery apparition. 32 minor planets were given permanent numbers entirely as a result of our observations. Our orbital investigations included the establishment of several hundred minor-planet identifications and the determination of preliminary orbits for the 1422 minor planets discovered in the course of the Palomar-Leiden T-3 survey. Following our discovery that two of the comets we observed, 1988e and 1988g, had practically identical orbits (but were separated by 76 days), we made a detailed study of their relationship.

(c) Observations are expected to continue much as usual as occasion demands. Orbit computations, ranging from preliminary computations for new objects, through rigorous least-squares differential corrections, including considered of planetary perturbations and (for comets) nongravitational effects, will also be made as appropriate.

(d) Observations have been published during the past year on 63 Minor Planet Circulars and 10 IAU Circulars. Orbits are on 169 MPCs and 30 IAUcs.

Astrometric Observations of Comets and Asteroids and Subsequent Orbital Investigations

Publications:

As far as observations are concerned, the MPCs have been declared a refereed journal, and observations from Oak Ridge plates are contained on MPC Nos. 12495-12496, 12499-12500, 12534, 12629, 12665, 12746-12750, 12776-12777, 12856-12860, 12862-12864, 12913-12915, 13003, 13005, 13007, 13021-13022, 13107-13111, 13134-13135, 13222-13224, 13239, 13355-13364, 13402, 13492-13493, 13538-13539, 13636-13640 and 13670-13671.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

The Radial Velocity Search for Extrasolar Planets

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
Space Sciences Building
University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Robert S. McMillan

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy: We are measuring small changes in the line-of-sight velocities of stars to detect the oscillating reflex acceleration that would be induced on the stars by large planets. To measure Doppler shift with the required sensitivity, we built a specially-designed optical spectrometer. The external (year-to-year) error of a one-hour exposure on a typical solar-type star of blue magnitude 4.0 is ± 12 m/s. On a star with $B = 5.5$ the error is ± 30 m/s per observation. We are observing both solar-type and K-giant stars. Our extensive data series show that these errors are random enough to "average down" through an observing season, giving accuracy adequate to detect planets of Jovian mass. Unlike the observations by Campbell et al. (1988 *Ap. J.*, 331, 902), our data do not require post-hoc velocity corrections derived from the stellar data.

b. Accomplishments: As of 1989 February 9 we have been observing intensively for 3.4 years. A total of 7716 observations of our 21 stars have been made on 325 nights. The internal precision, external accuracy, and uniformity of the observations have improved dramatically over the years, thanks to efficient feedback of the results of reduced data into the observing routine, extensive upgrades to the hardware and software, and the continued commitment by the same individuals to make the observations.

In addition to our efforts to detect planets orbiting solar-type stars, we are continuing our studies of the 2.2-day oscillation of the radial velocity of Arcturus (Smith et al. 1987 *Ap. J. (Lett.)*, 317, L79) and the modes of short-period oscillations in Pollux (ref. below). The Arcturus pulsation has been confirmed by Cochran (1988 *Ap. J.*, 334, 349), using a completely different instrument and technique. We are seeing slow velocity variations in some other stars, among them the K giant Epsilon Cygni A, which might be caused by modulation of spectral line profiles by stellar rotation, chromospheric activity, or the gravitational effect of stellar or planetary companion(s) (ref. below).

c. Anticipated Accomplishments: Our data show small velocity perturbations which should become clearer after additional years of observing. We propose to continue the observing program through at least 1990 to extend our time series to a significant fraction of the period of a planetary orbit or stellar activity cycle.

d. Publications:

- "Short Period Oscillations in Alpha Boo, Beta Gem, and Alpha Tau", 1988, P. H. Smith and R. S. McMillan, in Proc. IAU Symp. 132: The Impact of Very High S/N Spectroscopy on Stellar Physics (Dordrecht:Reidel), 291-294.
- "The Optical Fiber Feed of the LPL Radial Velocity Spectrometer", 1988, R. S. McMillan, M. L. Perry, P. H. Smith, and W. J. Merline, A. S. P. Conf. Ser. 3, "Fiber Optics in Astronomy", 237-246.
- "Accurate Accelerometry of Solar-Type Stars", 1987, P. H. Smith and R. S. McMillan, in Observational Astrophysics with High Precision Data, Proc. 27th Liege International Astrophys. Colloq., June 23-26, 1987 (Liege: Universite de Liege), 329-335.
- "A Radial Velocity Search for Extrasolar Planets", 1988, R. S. McMillan and P. H. Smith, in Proc. IAU Colloq. 99: Bioastronomy - The Next Steps, ed. G. Marx (Dordrecht: Kluwer), pp. 91-92.
- "Variation of the Radial Velocity of Epsilon Cygni", 1988, P. H. Smith, R. S. McMillan, W. J. Merline, and M. L. Perry, B. A. A. S., 20, 875.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE
Occultation Studies of the Solar System
NASA Grant NSG-7603

PERFORMING ORGANIZATION
Lowell Observatory
1400 West Mars Hill Road
Flagstaff, Arizona 86001

INVESTIGATOR'S NAME
Robert L. Millis

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy. Occultations of stars by planets, satellites, planetary ring systems, and asteroids, provide valuable opportunities to probe the Solar System in ways that are otherwise impossible from the surface of the Earth. For example, one can precisely measure the size and shape of objects which are much too small to be resolved directly, accurately map the structure and transparency of ring systems, and detect the faintest trace of an atmosphere by observing these elusive events. In this investigation, we identify upcoming occultations through wide-ranging computer searches, provide accurate predictions for the more important events, and observe selected occultations with our specially-designed portable photometric equipment.

b. Accomplishments. The premier accomplishment of this program during the past year was prediction and observation of the occultation of the star, P8, by Pluto on June 9, 1988. We devised and orchestrated a program of photographic astrometry involving researchers and instrumentation at Lick Observatory, the U.S. Naval Observatory's Flagstaff Station, and Lowell Observatory which permitted us to predict accurately the locations from which the rare Pluto event would be observable. The Kuiper Airborne Observatory (KAO) and our own portable equipment were deployed on the basis of these predictions and both succeeded in observing the occultation. The resulting data showed conclusively that Pluto has an atmosphere and gave convincing evidence of a haze layer which obscures the planet's limb. Furthermore, based on the same astrometric data used for the predictions, we have been able to better estimate the individual masses of Pluto and its satellite, Charon, and have demonstrated that Charon very probably has a spotted surface. Additionally, analysis of data from earlier occultations by the asteroids 47 Aglaja and 324 Bamberga was completed and papers submitted for publication.

c. Expected Accomplishments. Next year we expect to complete an analysis of all available observations of the Pluto occultation including those we obtained near Charters Towers, Queensland, Australia. This analysis is aimed at determining the global properties of Pluto's atmosphere and the extent of the haze layer. We intend to refine and extend the model which we used to derive the Pluto/Charon mass ratio from the astrometric data. In support of this effort, high resolution CCD imaging of the two bodies is planned to better determine their relative brightness as a function of the satellite's orbital position. We also plan to observe occultations of stars by Saturn's Rings, and the asteroids Kleopatra, Vesta, Ceres, and Brixia. The Saturn data will provide a valuable update on ring evolution since the Voyager encounters, while the asteroid observations will produce accurate estimates of the dimensions of these important minor planets. Finally, an extensive computer search for asteroid occultations occurring in 1990 and 1991 will be completed and published.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

A Search for Stellar Occultations by Uranus, Neptune, Pluto, and
Their Satellites: 1990-1999

PERFORMING ORGANIZATION

Smithsonian Astrophysical Observatory, Cambridge, Massachusetts

INVESTIGATOR'S NAME

Douglas J. Mink

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a) Strategy of Investigation

An occultation prediction software system will be used to search for occultations of stars in catalogs made from plates taken by Arnold Klemola, of Lick Observatory of the University of California at Santa Cruz. Other star catalogs, such as the Space Telescope Guide Star Catalog may be used to find fainter stars or for additional astrometry. Detailed predictions will be computed for events occurring between January 1990 and January 2000. Satellite orbits will be more accurately modelled before a search is conducted for occultations by such satellites as Triton and Charon.

b) Progress and accomplishments of prior year

In 1988, while this work was not supported directly by NASA, ephemeris models were improved and new astrometric measurements were utilized to refine predictions for the June 9 Pluto occultation, the observation of which provided a direct detection of Pluto's atmosphere. This occultation was first predicted in our 1985 paper, which gives the results of our previous, NASA-supported search.

c) What will be accomplished this year, as well as how and why

Following the taking and cataloging of plates, the automated search, and prediction computation, results will be published and disseminated to astronomers with the appropriate equipment to observe the occultations which are found. While Voyager 2 will have provided snapshot views of Uranus and Neptune, occultation measurements help refine models of these complex systems. Future occultations by Pluto will test models generated by analysis of the current series of mutual events with Charon. Catalogued stars are occulted so infrequently that a photographic plate search must be conducted to find observable events. The Space Telescope Guide Star Catalog will make searches easier, but additional plates are still needed to get accurate enough star positions for good predictions. The software and databases will also be used in support of other occultation observations, such as the occultation by Saturn and its rings of the bright star SAO 187255 on July 3, 1989.

d) Summary bibliography

"Predicted Occultations by Uranus, Neptune, and Pluto: 1985-1990", by Douglas J. Mink and Arnold Klemola, *Astronomical Journal* 90, pp.1894-1899, 1985.

"Occultations of SAO Stars and IRAS Point Sources by Planets: 1988-1999", By D.J. Mink, *Bulletin of the A.A.S.*, 19, p. 1150 (Abstract), 1987.

"Occultations by Pluto and Charon: 1980-1990", By D.J. Mink and A.R. Klemola, *Bulletin of the A.A.S.*, 20, p. 881 (Abstract), 1988.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

SYNTHETIC APERTURE PLANETARY RADAR ASTRONOMY USING THE
VERY LARGE ARRAY

PERFORMING ORGANIZATION

California Institute of Technology
Pasadena, California 91125

INVESTIGATOR'S NAME

Duane O. Muhleman

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

(a) We are developing a new way of doing planetary radar astronomy using the VLA to spatially map the radar echos from Mars, Venus, Saturn's Rings, Titan, Galilean Satellites and maybe a few asteroids. This technique yields maps of the entire surface without ambiguities, unlike the usual range rings and doppler strips technique which mainly senses the subearth point and relies on backscatter models for interpretation.

(b) This grant has only been funded since Nov 1988, but we obtained remarkable images of Saturn's rings in June 88 and even more remarkable images of Mars in Oct 88 in the form of 23 snapshots of about 12 minutes each. New radar features were found including strong reflections from the South Polar Ice Cap, the Tharus volcanos and no reflection from a region we named Stealth.

(c) During the remainder of this year and next, we will continue to work on the Mars and Saturn Ring images (although we are extremely short of funds for this purpose) and have 4 days scheduled on the VLA and JPL Goldstone 70 meter for a Titan experiment in June 89. We plan a Venus experiment for spring 1990 and, if any funds are available, Ganymede and Callisto mapping in the fall of 1990.

(d) Our Saturn Ring image was published in *Science News*, 134, 170 and some of our Mars images in *Science News*, 135, 75. Some Mars images are in press at *Astronomy* magazine.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

LUNAR AND PLANETARY STUDIES

PERFORMING ORGANIZATION

California Institute of Technology
Pasadena, CA 91125

INVESTIGATOR'S NAME

D.O. Muhleman, Principal Investigator
P. Goldreich, A.P. Ingersoll, J.A. Westphal, Co-P.I.'s

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

(a) The group carries out observational, theoretical, and model interpretations of Earth-based and spacecraft data on all of the planets and ring systems from the standpoint of the physics and chemistry of the solar system and planetology in general.

(b) During the last year, Muhleman's group has carried out cm-wavelength observations of Saturn, Uranus, Neptune, and the Galilean Satellites at the VLA with the goal of understanding the deep atmospheres of these major planets and Saturn's Rings. These data are combined with Owens Valley millimeter wave data on these objects to generate atmospheric thermal and abundance models, e.g., NH_3 distributions, etc. Goldreich, research fellows Longaretti and Murray and graduate student Banfield have been studying the evolution of the ring and satellite systems of Neptune. They have shown that the capture of Triton by Neptune would have resulted in the destruction of pre-existing satellites of Neptune and also in the perturbation of an inner satellite onto an orbit which makes it suitable for maintaining the Neptune arcs. Ingersoll and students continue their work on the circulations, energy budgets, temperatures, and cloud patterns in planetary atmospheres. Observations and numerical models of isolated vortices on the giant planets produced 3 papers in press. Io's supersonic circulation produced another paper in press. Professor Westphal has worked with two graduate students on observational projects involving the Galilean Satellites and planetary rings.

(c) Muhleman's graduate students will continue to work on the atmosphere of Saturn (Grossman) and Neptune (Hofstadter) during the next year although Mr. Grossman will complete his thesis work. Kathy Pierce is working on the atmosphere of Venus from the standpoint of CO and H_2SO_4 observations. Goldreich's group will continue to attack all of the ring problems and a new Research Fellow has joined the group, Dr. Renu Malhotra. Ingersoll will continue his studies of isolated vortices and of Io's atmosphere. He will work with Muhleman to understand the ammonia distributions observed in radio observations of the outer planets. He will work with Goldreich on generation of gravity waves by convection on Venus.

- (d) Berge, G.L., D.O. Muhleman and R.P. Lindfield, Very Large Array Observations of Uranus and 2.0 cm. *Astron. J.* **96**, 388-395, 1988.
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

SUBMILLIMETER AND MILLIMETER OBSERVATIONS OF SOLAR SYSTEM OBJECTS

PERFORMING ORGANIZATION

California Institute of Technology
Pasadena, California 91125

INVESTIGATOR'S NAME

Duane O. Muhleman

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

(a) This grant partially supports the observations at Caltech Millimeter Wave Observatories: The Millimeter array at the Owens Valley Radio Observatory and the Submillimeter Telescope on Mauna Kea. These observations are primarily microwave spectroscopy using the transitions of CO and HCN to study the atmospheres of Venus, Mars and Titan.

(b) We have completed a new synthesis of Venus in the CO(1-0) transition to map the Venus winds on the limbs and the altitudinal distribution of a function of local time on the evening and early night hemisphere of the planet. Kathy Pierce is leading this effort for her Ph.D. Thesis. We also spent 3 days measuring the CO in Titan, but the object is still too near the galactic center for a proper interpretation of the spectra in terms of the vital question of the CO abundance on Titan. Data have been taken for a new (and much improved) 3mm map of Saturn and the Rings similar to that published by Dowling, Muhleman and Berge, 1987. That work is part of Arie Grossman's thesis.

(c) We have scheduled 1 mm brightness temperature measurements of Pluto and Triton for Mar and Apr 1989, 2 important and unknown objects. If we can find the resources we will analyze our OVRO CO(1-0) measurements of Mars made in the fall, 1988.

(d) Dowling, T.E., D.O. Muhleman and G.L. Berge, Aperture Synthesis Observations of Saturn and Its Rings at 2.7mm Wavelength, *Icarus* 70, 506-516, 1987.
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

PHYSICAL PROCESSES IN COMETS

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

Ray L. Newburn, Jr.

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

A. STRATEGY In order to advance from global averages that define only mean cometary characteristics averaged over both space and time, it is necessary to obtain extensive two-dimensional photometry of gases and dust, in both visible and infrared wavelengths. Both a long time base and nearly simultaneous observations at the various wavelength are desirable. Modelling more sophisticated than the Haser paradigm must be introduced into the data reduction. My strategy is to achieve as many of these goals as possible by obtaining visible observations with Spinrad at Mt. Hamilton, IR observations with Hanner at Mauna Kea, and working on new modelling with Allen at JPL.

B. PROGRESS Hanner, Spinrad, and I have been cleaning up old observations made in the old way. Two papers are published (see PUBLICATIONS, next sheet), results on Bradfield (1987s) are nearly ready for submission, and results on Klemola (1987i) are being prepared for the Bamberg comet conference. Observations of Borrelly (1987p), Brooks 2 (1987m), and Nishikana-Takamizawa-Tago (1987c) are in preliminary stages of reduction. Two-inch optical quality interference filters have been procured and installed in the 3m Shane reflector for future observations under the new strategy.

C. PLANNED Reduction of all old observations will be completed and the results published. "New-strategy" observations will be taken of P/Brorsen-Metcalf this summer. Programs for reduction and modelling of this new data will be developed. Editorial work will be done on the review book from the Bamberg comet conference.

D. PUBLICATIONS

Hanner, M. S. and Newburn, R. L., "Infrared Photometry of Comet Wilson (1986) at Two Epochs," Astron. J. 97, 254-261, 1989.

Newburn, R. L. Jr. and Spinrad, H., "Spectrophotometry of 25 Comets: Post-Halley Updates for 17 Comets Plus New Observations for Eight Additional Comets," Astron. J. 97, 552-569, 1989.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Infrared Astronomy of Planetary Atmospheres

PERFORMING ORGANIZATION

Jet Propulsion Laboratory

INVESTIGATOR'S NAME

PI: Glenn Orton

Co-I's: Kevin Baines, James Friedson, Heidi Hammel

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

The goal of this effort is to acquire infrared astronomical data which supply key information on structures, compositions, and, indirectly, dynamics of planetary atmospheres. Our investigation is intended to complement and support planetary spacecraft experiments by providing (1) an informational context for analyzing spacecraft experiment data, (2) an quantitative baseline required for designing optimum spacecraft remote sensing and direct probing experiments and sequences, and (3) extension of observational coverage into spatial, temporal, spectral range and spectral resolution domains not covered by spacecraft experiments. Consequently, we assign priority to our proposed observations according to the degree to which they support specific planetary missions. In the past, we have supported the Voyager investigation at Uranus and Neptune. We are now making observations which will supplement Voyager Neptune atmospheric observations and which will support the Galileo mission at Jupiter and the proposed Cassini mission in the Saturn system.

For several years we have made thermal infrared maps of Jupiter at 7.8, 8.57, 10.57, 13.00, 18, 20, and 22 microns and Saturn at 7.8, 12.2, 18, 20 and 22 microns to derive temperature structures and information on cloud properties and composition. For Jupiter, emphasis is on mapping all longitudes once per year and on initiating a program of limited longitude and wavelength coverage on monthly time scales. We also continued near-infrared mapping of Jupiter and Saturn with emphasis on methane absorptions at 1.62 and 1.85 microns, ammonia absorption at 1.4-1.60 microns, and molecular hydrogen at 2.00-2.15 microns. We developed techniques for routine geometric rectification and calibration of the imaging data. We mapped a low-resolution spectrum of Uranus at 4.7 - 5.2 microns.

We plan to continue thermal infrared mapping of Jupiter and Saturn, with increasing emphasis on monitoring short-term behavior in addition to wavelength- and longitudinal-intensive coverage at opposition, paying particular attention to dramatic changes in the morphology of the jovian stratosphere in recent months. We will examine in more detail the extent to which phenomena observed in thermal infrared and visual/near-infrared data are correlated. This should provide a more complete and consistent picture of cloud structure and composition, as it relates to time-dependent activity for both Jupiter and Saturn. We will provide thermal infrared observations of Venus to coincide with the Galileo encounter to support PPR radiometric science. We will initiate high-resolution spectroscopic studies of the planets, starting with Neptune, and we will initiate studies of Titan at far-infrared through millimeter wavelengths. We will also re-examine the spectra of the giant planets and Venus in the latter region, partly to establish a uniform calibration scale.

Orton, G., J. Friedson, J. Caldwell, I. M. Avruch, and M. Malcom 1988. High-resolution features in the jovian stratospheric temperature field 1988. Bull. Amer. Astron. Soc. 20, 867.

Orton, G. S. and C. A. Kaminski 1989. An exploratory 5- μ m spectrum of Uranus. Icarus 77, 109-117.

Beebe, R., G. S. Orton and R. A. West 1989. Time-variability of clouds and temperatures: An observational perspective. In Time-Variable Phenomena of the Jovian System (Belton, Hunt and West, eds.) NASA Special Publication 494. In press.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Radar Investigation of Asteroids and Planetary Satellites

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena; CA 91109

INVESTIGATOR'S NAME

Steven J. Ostro

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy: Radar reconnaissance of near-Earth asteroids, mainbelt asteroids, the Galilean satellites, the Martian satellites, and the largest Saturnian satellites, using the Arecibo 13-cm and the Goldstone 3.5-cm systems. Measurements of echo strength, polarization, and delay/Doppler distribution of echo power provide information about dimensions, spin vector, large-scale topography, cm-to-m-scale morphology, and surface bulk density. The observations also yield refined estimates of target orbital elements.

b. Accomplishments: Radar signatures have been measured for 33 mainbelt asteroids and 18 near-Earth asteroids since this task began nine years ago. The dispersion in asteroid radar albedoes and circular polarization ratios is extreme, revealing huge differences in surface morphologies, bulk densities, and metal concentration. For the most part, correlation between radar signature and VIS/IR class is not high. Many near-Earth asteroids have extremely irregular, nonconvex shapes, but some have polar silhouettes that appear only slightly noncircular. The signatures of 1627 Ivar, 1986 DA, and the 180-km mainbelt asteroid 216 Kleopatra suggest bifurcated shapes.

Observational milestones during 1988 include (i) the first radar detection of Phobos, resulting in evidence that Mars's largest satellite has surface characteristics very different from the Moon's; (ii) the first high-SNR, dual-wavelength, dual-polarization, delay/Doppler observations of an asteroid, the space mission candidate 3980 (1980 PA); (iii) radar "ranging" to two mainbelt asteroids and two near-Earth asteroids, with resolutions as fine as 0.2 km; and (iv) the first 3.5-cm radar detections of Europa and Callisto and the first 70-cm radar detections of Ganymede and Callisto.

c. Anticipated Accomplishments during 1989: 1) Delay-Doppler imaging of the large, near-Earth asteroid 1580 Betulia. 2) First attempts to measure the 3.5-cm radar properties of mainbelt asteroids. 3) Extensive 3.5-cm, 13-cm, and 70-cm investigations of the Galilean satellites during the most favorable Jupiter opposition of the next ten years. 4) Initial radar observations of the newly discovered Apollo object 1988 TA and the prime space mission candidate 3361 Orpheus.

1988 Publications:

Ostro, S. J., Connelly, R., and Belkora, L.: Asteroid Shapes from Radar Echo Spectra: A New Theoretical Approach. *Icarus* 73, 24, 1988.

Ostro, S. J.: Radar Observations of Asteroids. Chapter in Asteroids II (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.), Univ. of Arizona Press (in press).

Magnusson, P., Barucci, M. A., Drummond, J., Lumme, K., Ostro, S. J., Surdej, J., Taylor, R., and Zappala, V.: Determination of Asteroid Shapes and Pole Orientations. Chapter in Asteroids II (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.), Univ. of Arizona Press (in press).

Ostro, S. J., Yeomans, D. K., Chodas, P. W., Goldstein, R. M., Jurgens, R. F., and Thompson, T. W.: Radar Observations of Asteroid 1986 JK. *Icarus* (in press).

Ostro, S. J., Jurgens, R. F., Yeomans, D. K., Standish, E. M., and Greiner, W.: Radar Detection of Phobos. Submitted to *Science*.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

SPECTROSCOPIC OBSERVATIONS OF THE PLANETS

PERFORMING ORGANIZATION

State University of New York at Stony Brook

INVESTIGATOR'S NAME

Tobias Owen

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a) Strategy: Using telescopes and spectrographs available at major observatories, spectroscopic observations of planets, satellites and comets are made to determine chemical and isotopic composition and physical parameters describing the local environments. Parts of this program are carried out in collaboration with other scientists, from France and from the U.S.S.R. as well as U.S. investigators.

b) Progress and Accomplishments: Last year, Owen, Maillard, de Bergh and Lutz published the discovery of deuterium on Mars in the form of HDO and an analysis of the observed enrichment of D/H in the Martian atmosphere. Reconciling this enrichment with geological requirements for large amounts of water at the Martian surface early in the planet's history appears to require a denser atmosphere and a warmer climate during that epoch in order to increase the hydrogen escape rate. We subsequently succeeded in detecting HDO on Venus, also for the first time. These data are not adequate for a good determination of D/H, however. We also detected CH₃D on Neptune and determined a value of D/H in Neptune's atmosphere. It appears that Neptune, like Uranus, shows evidence of contributions to the atmosphere from core material. Both of these objects exhibit values of D/H significantly higher than those found in the atmospheres of Jupiter and Saturn, supporting our contention that there are two distinct reservoirs of deuterium in the outer solar system. Graduate student Caitlin Griffith obtained new 5-micron spectra of Jupiter's Great Red Spot with the CGAS at the IRTF. Analysis is underway. Griffith also succeeded in detecting the pressure-induced absorption of N₂ in the spectrum of Titan. Further analysis is oriented toward determining the wavelength transparency of Titan's atmosphere in support of experiment development for the Cassini mission.

c) Plans for Coming Year: Analysis as described above will continue. Observing time is being requested at the CFHT to record the near-infrared spectrum of Triton at low resolution and to study HDO on Venus at high-resolution. Our preliminary attempt to do the latter experiment indicates that it should be easy, once weather and instrumental conditions are favorable.

d) Publications

"Deuterium on Mars: The Abundance of HDO and the Value of (D/H)" T. Owen, J. P. Maillard, C. de Bergh, and B. L. Lutz, Science 240, 1767 (1988).

"Monodeuterated Methane in the Outer Solar System III. Its Abundance on Titan" C. de Bergh, B. L. Lutz, T. Owen, and J. Chauville, Astrophys. J. 329, 951 (1988).

"Planetary Atmospheres" D. Hunten, R. Pepin, and T. Owen, in METEORITES AND THE EARLY SOLAR SYSTEM, eds. J. Kerridge and M. Matthews, University of Arizona Press (1988) pp 565-594.

"The 2.5 to 12 μ m spectrum of Comet Halley from the IKS-VEGA Experiment" M. Combes and 15 other authors including T. Owen, Icarus 76, 404 (1988).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Observational Studies of the Exospheres of Mercury and the Moon

PERFORMING ORGANIZATION

NASA Johnson Space Center
Houston, Texas 77058

INVESTIGATOR'S NAME

A. E. Potter

a. Strategy of Investigation. The atmospheres of the Moon and Mercury will be studied by means of high resolution spectroscopy of sodium and potassium resonance line emissions. The variation of abundances with location and time will be measured with a view to understanding the origin and evolution of the atmospheres.

b. Prior Accomplishments. During the past year, measurements of the spatial distribution of sodium on Mercury have continued. Sodium was found to be in excess in the polar regions, and was displaced to the terminator by radiation pressure. The polar excess appeared to be variable, suggesting an auroral origin. Sodium and potassium were discovered in the atmosphere of the Moon, and sodium was measured up to a lunar altitude of about one lunar radius. Analysis of these data demonstrated the existence of "cool" (400K) and "hot" (2200K) sodium in the atmosphere. The "hot" sodium is presumed to be that which has been freshly introduced by solar wind sputtering and/or meteoric impact. Analysis of the sources and sinks for sodium on the Moon suggest the existence of a strong sink, which is tentatively identified as condensation in the permanently shadowed regions of the Moon.

c. Planned Accomplishments. Work will continue on measurement of the abundance and spatial distribution of the sodium atmosphere of Mercury, using a newly-developed technique for imaging the whole planet in sodium emission by use of the image slicer and stellar spectrograph of the McMath telescope of the NSO. Correlations will be sought between sodium asymmetries and solar activity. Lunar sodium will be measured as a function of lunar phase to determine the relative importance of meteoric impact and solar wind sputtering. (The Moon is shielded from the solar wind at full moon). An effort will be made to extend measurements up to one lunar diameter altitude in order to detect a sodium coma around the Moon. Evidence for the existence of condensed volatiles in permanently shadowed regions of the Moon will be sought both by analysis of the sinks for sodium vapor, and by direct spectral measurements of these regions.

d. Bibliography.

Morgan, T. H., Zook, H.A., and Potter, A.E. 1988, "Impact Driven Supply of Sodium and Potassium to the Atmosphere of Mercury", Icarus, 75, 156

Potter, A.E. and Morgan, T.H. 1988, "Discovery of Sodium and Potassium Vapor in the Atmosphere of the Moon", Science, 241, 675.

Hunten, D.M., Morgan, T.H., and Shemansky, D.E. 1988, "Atmosphere of Mercury", Mercury, pp.562-612 (F. Vilas, C. Chapman and M.S. Matthews, eds.) University of Arizona Press, Tucson.

Potter, A.E. and Morgan, T.H. 1988, "Extended Sodium Exosphere of the Moon", Geophys. Res. Lett., 15, 1515.

PUBLICATIONS 1988-1989

- Morgan, T. H., Zook, H. A., and Potter, A. E. 1988, "Impact Driven Supply of Sodium and Potassium to the atmosphere of Mercury", Icarus, 75, 156.
- Potter, A. E. and Morgan, T. H. 1988, "Discovery of Sodium and Potassium Vapor in the Atmosphere of the Moon", Science, 241, 675.
- Hunten, D. M., Morgan, T. H., and Shemansky, D. E. 1988, "Atmosphere of Mercury" Mercury, 562 (C. Chapman and F. Vilas Eds.) University of Arizona Press, Tucson.
- Potter, A. E. and Morgan, T. H. 1988, "Extended Sodium Exosphere of the Moon", Geophys. Res. Lett., 15, 1515.
- Morgan, T. H., Zook, H. A., and Potter, A. E. 1989, "Production of Sodium Vapor from Exposed Regolith in the inner Solar System", Proc. Lun. Plan. Sci., 19, 297.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Fabry-Perot Ground-Based Observations of Comets and the Jupiter Plasma Torus

PERFORMING ORGANIZATION

Physics Department, University of Wisconsin, Madison, WI 53706

INVESTIGATOR'S NAME

F. Scherb and F. L. Roesler

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy: The Wisconsin 150 mm dual etalon Fabry-Perot spectrometer is a powerful instrument for the study of diffuse emission sources such as cometary atmospheres, the Jupiter plasma torus, and various emission nebulae. Since 1985, we have concentrated our efforts on extensive observations of comet Halley and the analysis of the data.

b. Accomplishments: Images of comet Halley in [OI]6300Å emission were analyzed to obtain the spatial distribution of $O(^1D)$ in the cometary atmosphere. The narrow spectral bandpass of the Fabry-Perot (0.2Å) eliminated contamination from terrestrial airglow [OI]6300 and cometary NH_2 lines in the nearby spectrum. The results were modeled to provide photodestruction lifetimes of cometary H_2O and OH, the predominant parents of $O(^1D)$.

The Fabry-Perot was also used in the scanning mode to obtain measurements of [OI]6300 and Balmer alpha ($H\alpha$) emissions which were used to determine the H, $O(^1D)$ and H_2O production rates as a function of heliocentric distance, both pre-perihelion and post-perihelion. We have also analyzed our high resolution spectra of the NH_2 (0,8,0) band in the 6300Å region to obtain preliminary values of the NH_2 production rate. Assuming NH_3 is the major parent of NH_2 , we find that the abundance ratio NH_3/H_2O is about $(0.12 \pm 0.04)\%$, assuming thermal equilibrium for the level populations of NH_2 .

Scans of the H_2O^+ (0,8,0) band spin doublet at 6158.64Å and 6158.86Å were used to obtain H_2O^+ emission intensities and ion accelerations in the coma and along the ion tail of the comet. The ion acceleration was approximately constant along the tail on each night, but varied from night to night.

c. Anticipated Accomplishments: Much of the imaging data from comet Halley remains to be analyzed. We are now completing the installation of an image processing system on our computer to facilitate this analysis.

K. Magee-Sauer completed her Ph.D. thesis in May, 1988. We are now preparing several papers for submission to Icarus before she leaves in August 1988 for her new position at Bartol Research Foundation.

We have established a collaboration with W. Smyth of AER, who will use an advanced Monte Carlo model of the cometary atmosphere to analyze our $H\alpha$ and [OI]6300 data.

We have recently acquired a CCD camera from Photometrics, Ltd. We plan to use the new camera with the 150 mm Fabry-Perot to carry out a new series of observations of the Jupiter plasma torus at Kitt Peak in November-December, 1988.

Publications

Magee-Sauer, K., F. L. Roesler, F. Scherb, J. Harlander, and R. J. Oliverson, "Spatial Distribution of $O(^1D)$ from Comet Halley", Icarus, 76, 89 (1988).

Magee-Sauer, K., F. Scherb, F. L. Roesler, and J. Harlander, "Fabry-Perot Observations of NH_2 Emission from Comet Halley", submitted to Icarus (1988).

Magee-Sauer, K., F. Scherb, F. L. Roesler, and J. Harlander, "Comet Halley $O(^1D)$, H, and H_2O Production Rates", submitted to Icarus (1988).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

STUDIES IN PLANETARY SCIENCES

PERFORMING ORGANIZATION

LUNAR AND PLANETARY LABORATORY
UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85721

INVESTIGATOR'S NAME

DR. BRADFORD A. SMITH

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

- a. This is primarily a study of the very early and very late evolution of planetary systems. It involves a search for optically identifiable young or evolved circumstellar disks, studies of circumstellar material surrounding young and old stellar systems and a detailed study of the Beta Pictoris system.
- b. With the completion of a January observing run at the CFHT, the last quadrant of sky was covered in a search for Beta Pictoris type circumstellar disks. More than 125 stars closer than 100 KPC have now been imaged with the Arizona coronagraph. Studies of bipolar lobes in both very young and very old systems have demonstrated the value of the coronagraph in identifying and characterizing previously unseen material surrounding the central stars. These observations have involved both morphology and polarization. New observations of the Beta Pictoris disk obtained at ESO and Las Campanas Observatory in December and January will answer questions related to the wavelength dependence of polarization and the NE/SW asymmetry.
- d. We are now beginning the batch processing of images involving more than 125 stars in a search for circumstellar disks. We are also reducing polarization observations of young and old stellar systems exhibiting extensively dispersed circumstellar dust and polarization measurements of the Beta Pictoris disk. Our objectives are to determine the relative abundance of conspicuous circumstellar disks, to characterize their physical properties and to investigate the morphology and grain characteristics of young and old systems which involve bi-polar outflow.

The Beta Pictoris Disk (1988). B.A. Smith, John Fountain (University of Arizona) and R.J. Terrile, (Jet Propulsion Laboratory). BAAS, Vol. 20 No. 3, 875.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

RADIO ASTRONOMICAL STUDIES OF COMETS WITH THE VERY LARGE ARRAY

PERFORMING ORGANIZATION

Department of Astronomy, University of Illinois
341 Astronomy Building, 1011 W. Springfield Avenue
Urbana, Illinois 61801

INVESTIGATOR'S NAME

Lewis E. Snyder (P.I.) and Patrick Palmer (Co-P.I.)

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

A) We are using the VLA to study the composition, velocity distribution, maser excitation, and plasma interactions of cometary gas. We have worked with Prof. de Pater (Berkeley) to map OH emission from comets Halley and Wilson (19861), and to detect formaldehyde (H_2CO) emission from Halley. As future comets appear, we plan to continue our VLA observations and compare them to the Halley results in order to establish the degree of uniqueness, if any, of Comet Halley.

B) Immediately prior to the start of this grant, our successful radio images of OH emission from Comet Halley demonstrated for the first time that the VLA can be used for cometary research. Similar observational techniques were employed at the VLA to detect H_2CO emission from Comet Halley. In addition, we completed the analysis of OH in Comet Wilson (19861); searched for OH in Comet Liller; and searched for OH and H_2CO in Comet Machholz.

C) Much of the remaining cometary data analysis will be completed. For example, we have unreduced OH data for Comet Liller (1988a). Normally we would expect to find an OH production rate comparable to that of Comet Halley. However, the OH maser inversion measure was always strongly positive during our Halley observations, but very close to zero during the Liller observations. Thus if the OH maser is controlled only by the Swings UV pump, we should see no OH emission from Liller, but if other pumping mechanisms are at work, then OH maser emission may be detected. Clearly, the low inversion measure makes Comet Liller interesting.

Last September, we observed Comet Machholz in OH at 18 cm. wavelength and in H_2CO at 6 cm. wavelength. The data reduction has been tedious because solar interference caused severe problems at the OH wavelength. However, because of the shorter wavelength, the H_2CO data appear to be relatively free of interference and the analysis should be completed this year.

As VLA time becomes available, we plan to search Comet Brorsen-Metcalf for cyanoacetylene (HC_3N), which is of immediate interest because it may be a reservoir of carbon and a source of cometary CN.

- D) Palmer, P., de Pater, I., and Snyder, L. E., 1987, IAU Circular No. 4314, "COMET WILSON (19861)".
- de Pater, I., Palmer, P., Snyder, L. E., and Ip, W.-H., 1986, "VLA Observations of Comet Halley: The Brightness Distribution of OH around the Comet", in Proceedings of 20th ESLAB Symposium on the Exploration of Halley's Comet, Heidelberg, (ESA SP-250) 409.
- de Pater, I., Palmer, P., and Snyder, L. E., 1986, "The First Radio Images of OH Emission from Comet Halley", in Cometary Radio Astronomy, eds. W. M. Irvine, F. P. Schloerb, and L. Tacconi-Garman (Green Bank, WV: NRAO Workshop No. 17) 159.
- Snyder, L. E., Palmer, P., and de Pater, I., 1989, "Radio Detection of Formaldehyde Emission from Comet Halley", Astron. J., 97, 246.
- Palmer, P., de Pater, I., and Snyder, L. E., 1989, "Observations of the OH Emission from Comet Wilson (19861): The Value of High Resolution in Both Spatial and Velocity Coordinates", Astron. J., in press.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Astronomy

PERFORMING ORGANIZATION

California Institute of Technology
Pasadena, CA 91125

INVESTIGATOR'S NAME

B. T. Soifer, Senior Research Associate in Physics

DESCRIPTION (a. Brief statement on strategy of investigation. b. Progress and accomplishments of prior year. c. What will be accomplished this year, or how, as how and why, and d. Summary bibliography)

a) Strategy

A wide range of observational studies are carried out to improve our understanding of the bodies and ring systems of the outer solar system. Using the 200-inch Hale telescope, near-infrared observations are made of Jupiter, Saturn, Uranus, Neptune, and the Pluto-Charon system. High time resolution occultation observations of the Uranus Ring system are used to study in detail the dynamics of this system. Occultation studies of Neptune are probing this intriguing "ring-arc" system. Occultation observations of the Pluto-Charon system probe the surface properties of these distant bodies. In addition, the plate material of the PSSII survey is being used to search for new comets and asteroids.

b) Accomplishments

We observed at $2.2\mu\text{m}$ one Neptune Stellar occultation on 9 July 88, obtaining good data over the entire event. No clear arc ring events were found in this occultation. Two Pluto-Charon mutual eclipse events, those of 30 Mar 88 and 3 May 88, were observed in the near infrared. The observations of the superior event, compared to previous observations, will permit the comparison of the global properties of the hemispheres of Charon. The observations of the inferior event provide adequate resolution to distinguish surface features of the southern hemisphere of Pluto. Plates of the Palomar Sky Survey II have been scanned to search for new asteroids and comets.

Using a newly developed near infrared camera, we obtained images of Jupiter and its ring system in the broadband $2.2\mu\text{m}$ filter and in the $2.3\mu\text{m}$ absorption band of methane. The disk features seen in the broadband images disappear in the methane images. The ring of Jupiter and its shepharding satellites were seen in the $2.3\mu\text{m}$ images. The longitude of the shepharding satellites for the ring, Adrastea and Metis, were found to be different by $\sim 20^\circ$ from the ephemerides derived from the Voyager data. These results will allow a factor of 10 improvement in the orbits of these satellites.

c) Anticipated Accomplishments

We shall continue the observational programs carried out in the last year. Using the near infrared camera on the 200 inch Hale telescope, we shall observe the 2 July 89 occultation of the bright star 28 Sgr by Saturn's rings. This observation, to be conducted at $3.4\mu\text{m}$, will allow us: to derive the optical depth profiles of the entire ring system to refine the estimate of the thickness of the rings, to refine precession rates for ring features found by Voyager to improve the determination of Saturn's higher order gravitational harmonics, and to determine the distribution of particle sizes in the range of 1-30 cm.

We shall search for the arc rings of Neptune and/or shepharding satellites by imaging the planetary system when it is well away from the Milky Way in April 1989. This will be the best opportunity to detect these bodies before the Voyager encounter of August. We shall also observe the occultation by Charon of the south pole of Pluto. In addition, we shall continue our search for new asteroids and comets using the plates of the PSS II.

d) Publications

Nicholson, P. D., Cook, M. L., Matthews, K., Elias, J. H., and Gilmore, G. 1989, *Icarus*, in press.

Nicholson, P. D., McLeod, B. A., Gilmore, G., Buie, M., and Matthews, K. 1988, "Near Infrared Stellar-Occultative Predictions for Uranus and Neptune: 1987-1990", *A.J.* 95, 562.

Kowal, C.T., 1989, "A Solar System Survey", *Icarus*, 77, 118.

IAU Circulars

4549 Comet Maury-Phinney (1988c)

4550 Comet Maury-Phinney

4662 1988 TA

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Spatially Resolved Quantitative Spectroscopy and Imaging of Comets

PERFORMING ORGANIZATION

University of California, Berkeley

INVESTIGATOR'S NAME

Hyron Spinrad

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

- (1) Although the last year was devoid of any bright comet, re-analysis of older dust and gas production rate data with the benefit (hindsight) of the 1986 P/Halley apparition has been completed (with R.L. Newburn). We've changed some of the physical assumptions which were used in the previous interpretations of our IDS and long-slit CCD spectrophotometry.

Many comets, perhaps all of them, have nuclei that are larger and darker than previously assumed. The nucleus itself does make a significant contribution to the continuum light of the inner coma, and its gravitational deceleration on the escaping dust is no longer negligible. These two factors and the new size-distribution of dust grains slightly modify the dust production rates calculated by NSII (1985).

The gas production rates for the comets have also been improved: the CN emission rate factors were updated from Tatum (1984) and more important, a full Haser-model formulation for Q(OI) has replaced the approximation suggested by Spinrad (1982). The conversion of oxygen to total water production rates now includes an actual measure of the solar Ly α flux to explicitly assess the water photo-dissociation by line radiation. The dominant water production rates derived for P/Halley seem quite secure.

- (2) An unanticipated result, still under analysis, is the long-slit observation that there exists measurable offset in the dust/gas emission peaks along the "sun-fans" of comets P/Tempel-2 and IRAS-Araki-Alcock. The sharp dust maxima peaks, presumably at the projected nuclear position, lag the maxima of C₂, (OI), and NH₂ molecules by up to 2000km [although its typically only 500km for (OI)]. This "decoupling" of gas and dust hasn't been satisfactorily interpreted yet.

My main new area for cometary research in the proposal year will be to focus on a search for unidentified potential parent molecules [like the important volatile gases CO and HCO] by studying their quantitative concentration toward the cometary nucleus. By the start of the time period relevant to this proposal continuation [Dec. 1989], we should have obtained unusually high-resolution spectral and spatial observations of Comet P/Brorsen-Metcalf. This will be done with the new Hamilton Echelle spectrograph on the Lick 3-m reflector. These echellograms will require new processing techniques, but hopefully will prove an order-of-magnitude superior in the search for new molecular lines which are very concentrated to the cometary nucleus, and thus must be processed from the heavily dust-contaminated inner coma spectra. The combination of high spectral purity ($\lambda/\Delta\lambda > 10^4$) and good angular resolution ($\leq 1''$) and a linear (CCD) detector should do the job.

Publications

C₂ In Comet Halley: Evidence For Its Being Third Generation and Resolution of the Vibrational Population Discrepancy, *Ap.J.*, **334**, 476, 1988 (with C.R. O'Dell, R.R. Robinson, K.S. Krishna Swamy, and P.J. McCarthy).

Spectrophotometry of 25 Comets: Post-Halley updates for 17 Comets plus New Observations for 8 Additional Comets, *Astron.J.*, (Feb. 1989, in press), with R.L. Newburn.

A CCD Observation of the Water Ion Distribution in the Coma of Comet Halley near the Giotto Encounter, *Astron. and Ap.*, 1988 (in press), with W-H. Ip and P. McCarthy.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

ASTEROID SHAPES AND POLE ORIENTATIONS FROM VISUAL AND INFRARED PHOTOMETRY

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

INVESTIGATOR'S NAME

Edward F. Tedesco

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

- a. STRATEGY:** 1. To obtain visual and infrared lightcurves of Pluto-Charon mutual eclipse event lightcurves and to analyze them to derive models of the Pluto-Charon system, including separations, relative sizes, some orbital parameters, system density, and an albedo map of the hemisphere of Pluto facing Charon. 2. To obtain visual and infrared photometry of selected asteroids to help determine their albedos, sizes, shapes, pole orientations, taxonomic classes, and phase functions.
- b. ACCOMPLISHMENTS:** During 1988 observations of Pluto-Charon mutual events were obtained with the Palomar 1.5 (2/7) and 5-meter (2/3), Kitt Peak 1.3-meter (0/4), and NASA IRTF 3-meter (4/7) telescopes (the pair of numbers in parentheses indicates the number of nights useful data were obtained and the number of nights assigned, respectively). Infrared lightcurves of two asteroids were obtained and used to demonstrate that their visual lightcurves were due primarily to their irregular shapes (Lebofsky et al., 1988). The PI's participation in a paper on collaborative IRTF radiometry of near-Earth asteroids (Veeder et al., 1989) and the writing of three chapters for the Asteroids II book (Gradie et al., 1989, Tedesco, 1989a and 1989b) were supported by this grant.
- c. ANTICIPATED ACCOMPLISHMENTS:** During 1989 we will make additional visual and infrared mutual event lightcurve observations, hold a fifth Pluto Workshop at the 1989 DPS meeting, and continue coordination of the international campaign and publication of the Pluto newsletter. Next year we will complete reduction of all the visual data obtained to date and publish a visual lightcurve data paper. The IRTF and Palomar Pluto infrared data will be published together with an analysis. The following year we will publish an analysis of the visual data using a second-order eclipse model. We have telescope time during 1989 to obtain visual and infrared lightcurves of the near-Earth asteroid 1580 Betulia.

d. PUBLICATIONS:

- Gradie, J.C., Chapman, C.R., and Tedesco, E.F. (1989). Distribution of taxonomic classes and the compositional structure of the asteroid belt. In Asteroids II (R.P. Binzel, T. Gehrels, and M.S. Matthews, eds.), in press.
- Lebofsky, L.A., Greenberg, R., Tedesco, E.F., and Veeder, G.J. (1988). Infrared lightcurves of asteroids 532 Herculina and 45 Eugenia: Proof of the absence of significant albedo markings. *Icarus* **75**, 518-526.
- Tedesco, E.F. (1989a). Introduction to the Asteroids II data base. In Asteroids II (R.P. Binzel, T. Gehrels, and M.S. Matthews, eds.), in press.
- Tedesco, E.F. (1989b). Asteroid magnitudes, UBV colors, and IRAS albedos and diameters. In Asteroids II (R.P. Binzel, T. Gehrels, and M.S. Matthews, eds.), in press.
- Veeder, G.J., Hanner, M.S., Matson, D.L., Tedesco, E.F., Lebofsky, L.A., and Tokunaga, A.T. (1989). Radiometry of near-Earth asteroids. *Astron. J.*, in press.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Optical and Infrared Imaging

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
Oak Grove Drive
Pasadena, California 91109

INVESTIGATOR'S NAME

Richard J. Terrile

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

A. OBJECTIVES: The purpose of this investigation is to obtain and analyze high spatial resolution CCD coronagraphic images of extra-solar planetary material and solar system objects. These data will provide information on the distribution of planetary and proto-planetary material around nearby stars leading to a better understanding of the origin and evolution of the solar system. Imaging within our solar system will provide information on the current cloud configurations on the outer planets, search for new objects around the outer planets, and provide direct support for Voyager, Galileo, and CRAF by imaging material around asteroids and clouds on Neptune.

B. ACCOMPLISHMENTS: Over the last year this program acquired multispectral and polarization images of the disk of material around the nearby star Beta Pictoris. This material is believed to be associated with the formation of planets and provides a first look at a planetary system much younger than our own. Preliminary color and polarization data suggest that the material is very low albedo and similar to dark outer solar system carbon rich material. A coronagraphic search for other systems is underway and has already examined over 100 nearby stars. Coronagraphic imaging provided the first clear look at the rings of Uranus and albedo limits for the ring arcs around Neptune.

C. PROPOSED RESEARCH: A survey of the nearby stars will be continued and data will be examined more deeply to provide limits on the probability of circumstellar material around stars and to understand the morphology of young planetary systems. Further imaging of the Beta Pictoris system is planned to obtain polarization data as a function of color. These data will allow a measurement of the particle size distribution of dust in the disk. Coronagraphic imaging of the outer planets, asteroids and star forming regions will continue to provide support for ongoing missions such as Voyager, Galileo, CRAF, Cassini and CIT.

D. SUMMARY BIBLIOGRAPHY: 5 abstracts published, 2 papers in preparation.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

PHYSICAL PROPERTIES OF ASTEROIDS

PERFORMING ORGANIZATION

JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CA. 91109

INVESTIGATOR'S NAME

Glenn J. Veeder

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy: Infrared photometry at 1.2, 1.6 and 2.2 microns provides a relatively rapid and accurate method for the classification of asteroids and is important for comparison with laboratory measurements of meteorites and other possible compositional analogues. Extension beyond the visual is especially useful for minerals which have strong characteristic infrared colors such as olivine in the A class asteroids. Radiometry at long infrared wavelengths [e.g., 10 microns] is important for deriving basic physical parameters via thermal models such as size and albedo which in turn enables the conversion of relative colors to absolute reflectances. In particular, albedos are the only way to distinguish among the otherwise ambiguous E, M and P classes of asteroids.

b. Progress: We obtained JHK infrared observations of 16 asteroids at the NASA Infrared Telescope Facility (IRTF) on Mauna Kea during 1988. Preliminary results on the Eos family were presented at the DPS meeting in Austin. We have published an analysis of 22 Aten, Apollo and Amor asteroids. Our results include albedos and diameters for these objects as well as the identification of the first known class M and class E near-Earth asteroids. The "standard" thermal model appears to be inadequate for some of these small asteroids because of their coarse regolith so we have therefore constructed a rotating thermal model for such asteroids. We have identified several anomalous IRAS asteroids.

c. Anticipated Accomplishments: We are now reducing JHK photometry from our survey of the main belt. We will continue JHK observations of the Eos family. From this work we expect to examine whether Eos asteroids are related to the parent bodies of ordinary chondritic meteorites. We will initiate a mini-survey of the Hungaria family at JHK in order to identify high albedo candidates for follow-up at N. We will also study selected unusual IRAS asteroids. We will exploit the new SUMP facility at the IRTF by developing the capability to derive accurate visual/infrared colors. SUMP will allow us to eliminate uncertainties due to large lightcurve variations of irregular asteroids. This sub-micron system will also permit us to refine our thermal models in order to investigate the metallic phase in the regolith of some asteroids.

d. Publications

Veeder, G.J., Hanner, M.S., Matson, D.L., Tedesco, E.F.,
Lebofsky, L.A., and Tokunaga, A.T.: Radiometry of Near-Earth
Asteroids. *Astronomical J.*, in press.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Passive Microwave Remote Sensing of the Asteroids Using the VLA

PERFORMING ORGANIZATION

Geophysics Branch (Code 622)
Goddard Space Flight Center
Greenbelt, MD 20771

INVESTIGATOR'S NAME

William J. Webster, Jr.

DESCRIPTION (a. Brief statement on strategy of investigation. b. Progress and accomplishments of prior year. c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

- a. Precise flux density measurements made with the Very Large Array (VLA) of the National Radio Astronomy Observatory will be used to define the microwave continuum spectra of asteroids. These spectra will be inverted in order to estimate the near-surface bulk properties (radii, roughness, composition) independent of previous optical or infrared spectroscopy.
- b. The results on 15 Eunomia and 704 Interamnia have been published. The paper on 1 Ceres has been published in the AJ. A paper on the simple models of asteroid radio spectra has been published in the Publications of the Astronomical Society of the Pacific. Preliminary analyses of 2 Pallas, 4 Vesta and 10 Hygeia have been submitted to the AJ. A review chapter for Asteroid II is in press. A paper on the emissivity of Ceres and Vesta is in press in the Publications of the Astronomical Society of the Pacific.
- c. The continuum spectrum of Vesta implies a variable depth surface layer. We have obtained a high resolution 2cm (14.9GHz) map of Vesta which we are analyzing for the spatial variation of the surface dielectric properties and surface layer apparent depth. We plan observations at 86GHz and 226GHz of Ceres, Pallas, Vesta and Hygiea to improve the determinations of the spectral gradient in the mm-to-cm wavelength transition. We will begin a survey of the 1.3 mm emission of the main belt asteroids in cooperation with W. Altenhoff of MPI.
- d. Summary Bibliography:
Webster, W.J., Jr., Hobbs, R.W. and Lowman, P.D., Jr. (1984), Detection of $\lambda = 2$ cm Emission from Minor Planet 15 Eunomia, Icarus, 60, 538.
Webster, W.J., Jr., Hobbs, R.W. and Lowman, P.D., Jr. (1987), Detection of $\lambda = 2$ cm Emission from Minor Planet 704 Interamnia, Icarus, 69, 29.
Webster, W.J., Jr. (1987, On the Simple Models for the Interpretation of Centimeter-Wavelength Radio Observations of Asteroids, PASP, 99, 1009.
Webster, W.J., Jr., Johnston, K.J., Hobbs, R.W., Wade, C.M., Lowman, P.D., Jr., and Seidelman, P.K. (1988), The microwave spectrum of Asteroid 1 Ceres, Astronomical Journal, 95, 1263.

FY 1988 Publications

- Webster, W.J., Jr. (1987, On the Simple Models for the Interpretation of Centimeter-Wavelength Radio Observations of Asteroids, PASP, 99, 1009.
- Webster, W.J., Jr., Johnston, K.J., Hobbs, R.W., Wade, C.M., Lowman, P.D., Jr., and Seidleman, P.K. (1988), The microwave spectrum of Asteroid 1 Ceres, Astronomical Journal, 95, 1263.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Astrometric Observations of Asteroids and Small Bodies

PERFORMING ORGANIZATION

Jet Propulsion Laboratory

INVESTIGATOR'S NAME

James G. Williams

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a) Objectives: Comets and asteroids are observed with the Palomar 1.5m telescope using a CCD array. The goal is observations of astrometric quality (the reduction to positions is separately funded) and the priorities are comets plus minor planets which are planet crossers, Trojans, Hildas, have high inclinations, or otherwise have unusual orbits. The stress is on recoveries of comets and asteroids seen at previous oppositions and follow up on newly discovered objects. Surveys and new discoveries are not being attempted. The modest amount of available dark time is used for faint objects, while brighter objects can be followed in the more plentiful light time. Since asteroids are usually discovered near perihelion when bright, the next several opportunities for recovery are normally fainter. Thus big telescopes complement discoveries by smaller instruments.

b) Progress: During the past nine months four periodic comets were recovered. They were P/Churyumov-Gerasimenko (1988i), P/Russell 3 (1989d), P/Pons-Winnecke (1989g), and P/Clark (1989h). The first was a shared recovery. A follow up observation of the newly-discovered comet Shoemaker-Holt-Rodriquez (1988h) appeared on an IAU card as did the recoveries of the Amor asteroid 1980 PA (now numbered 3908) and the Apollo asteroids 1979 VA and 1987 SY. The cards also reported that Schwassmann-Wachmann 1 was in outburst in May and June of 1988. A variety of additional comets and interesting asteroids, including more than a dozen planet crossers, were also recorded.

c) Proposed Research: The CCD observing program on the 1.5m Palomar telescope will be continued for the recovery of faint comets and minor planets. The priorities will emphasize first opposition follow up and second opposition recovery. Comets and planet crossing and other unusual asteroids will be given priority. This is not a survey program.

Publications

Astrometric Observations of Asteroids and Small Bodies

Comet and asteroid recoveries and other time-critical observations were published on International Astronomical Union Card numbers 4606, 4619, 4625, 4627, 4637, 4662, 4710, 4731, 4736, 4737, and 4742.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Spectroscopy of Comets

PERFORMING ORGANIZATION

Department of Physics and Astronomy
Arizona State University
Tempe, AZ 85287

INVESTIGATOR'S NAME

Susan Wyckoff
Peter Wehinger

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

Strategy - Observations of NH_2 , [OI] and molecular ion spectra in comets represent ionization and dissociation products of virtually all of the volatile fraction of a comet nucleus, and can provide abundances of N_2 , NH_3 , H_2O , CO_2 , and CO . The primary objective is to 1) determine these abundances in a sample of comets, and 2) to improve the models used to compute the abundances, with the ultimate goal to significantly constrain models of comet formation and the primitive solar nebula.

Accomplishments - The carbon isotope abundance ratio, $^{12}\text{C}/^{13}\text{C} = 65 \pm 8$ has been determined for comet Halley from resolved rotational line structure in the B-X CN (0,0) band. This ratio is $\sim 30\%$ lower than the solar system value, 89, indicating either an enhancement of ^{13}CN or a depletion of ^{12}CN in the comet. Scenarios consistent with the observed carbon isotope ratio are: 1) formation of the comet at the periphery of the solar nebula in a fractionation-enriched ^{13}CN region, or hidden from ^{12}CN enrichment sources, and 2) capture of an interstellar comet.

Fluorescence efficiencies have been calculated for NH_2 , and the ammonia abundance for comet Halley derived. We find $\text{NH}_3/\text{H}_2\text{O} = 0.005 \pm 0.002$, in good agreement with the results obtained from modeling the GIOTTO ion mass spectrometer data (Allen *et al.* 1987). Ammonia abundances determined for five comets indicate a significant range ~ 10 , in the $\text{NH}_3/\text{H}_2\text{O}$ ratios.

Analysis of pre- and post-perihelion spectra of comet Giacobini-Zinner using a Monte Carlo model confirm the low $\text{C}_2/\text{H}_2\text{O}$ ratio, and indicate a very low $\text{NH}_3/\text{H}_2\text{O}$ ratio. Moreover, we show that neither Na^+ nor C_2^+ can account for the strong signal detected at 23-24 amu in the ICE spacecraft mass spectrometer data.

In Progress - Fluorescence efficiencies and column densities are being determined for the following molecular ions observed in the plasma tails of comets: CO_2^+ , CO^+ , CH^+ , OH^+ , H_2O^+ and N^+_2 . The relative abundance of N_2/NH_3 in comets will be used to provide constraints on models of the primitive solar nebula.

A monte carlo model of a comet coma is being developed which incorporates a time varying source and collisions. Asymmetric vaporization and radiation pressure effects will also be included in the model. Spatial profiles and abundances derived from long-slit spectra of comets will be used together with the spacecraft results, to constrain the model. The model is intended to improve productions rates determined for species with relatively short scale lengths in comets of moderately large productions rates.

An observational program to obtain long-slit spectra of comets using large telescopes is intended to establish a statistical base of cometary abundances. The determination of isotope ratios in a bright comet of opportunity and comet Brorsen-Metcalf is a high priority objective of this program.

RELEVANT PUBLICATIONS IN OR SUBMITTED TO REFEREED JOURNALS
(1988 January - 1989 January)

1. Wyckoff, S., Tegler, S., Wehinger, P.A., Spinrad, H. and Belton, M. J. S.: Abundances in Comet Halley at the Time of the Spacecraft Encounters. Ap. J., 325, 927-938, 1988.
2. Wyckoff, S., Tegler, S. and Engel, L.: Ammonia Abundances in Comets. Adv. Space Res., 6, in press, 1988.
3. Wyckoff, S. and Lindholm, E.: On the Carbon and Nitrogen Isotope Abundance Ratios in Comet Halley. Adv. Space Res., 6, in press, 1988.
4. Wyckoff, S. and Theobald, J.: Molecular Ions in Comets. Adv. Space Res., 6, in press, 1988.
5. Konno, I. and Wyckoff, S.: Atomic and Molecular Abundances in Comet P/Giacobini-Zinner. Adv. Space Res., 6, in press, 1988.
6. Wyckoff, S., Lindholm, E., Wehinger, P. A., Peterson, B., Zucconi, J-M., and Festou, M.: The $^{12}\text{C}/^{13}\text{C}$ Abundance Ratio in Comet Halley. Ap. J., 327, 1 Apr., 1989.
7. Wyckoff, S. and Lindholm, E.: On the Carbon and Nitrogen Isotope Abundances in Comet Halley. Astron. J., in press, 1989.
8. Lindholm, E. and Wyckoff, S.: Measurement of the Plasma Acceleration in Comet Halley. Ap. J., in press, 1989.
9. Tegler, S. and Wyckoff, S.: Fluorescence Efficiencies of NH_2 . Ap. J., 1 Aug., 1989.
10. Konno, I. and Wyckoff, S.: Observations of Comet P/Giacobini-Zinner Before, During and After the ICE Spacecraft Encounter. Ap. J., in press, 1989.
11. Konno, I. and Wyckoff, S.: Abundances in Comet P/Giacobini-Zinner using a Monte Carlo Model. Ap. J., in press, 1989.
12. Wyckoff, S.: Cometary Clues to the Origin of the Solar System. Earth Sci. Reviews, in press, 1989.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Comet and Asteroid Dynamics

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
Pasadena, CA 91109

INVESTIGATOR'S NAME

Donald K. Yeomans

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy: In order to provide observers with accurate ephemerides of comets and asteroids, up-to-date astrometric positions must be used to improve the existing orbits. For active comets, nongravitational forces must be taken into account; these forces are assumed due to the rocket-like effect of outgassing cometary ices and are used to characterize the volatility and rotation properties of icy cometary nuclei. In an effort to improve ephemeris accuracies, the benefits of a new nongravitational force model for comets are being investigated and radar data are being used as a new data type for asteroid orbit improvement.

b. Accomplishments: A new paradigm for the cometary nongravitational force model has been employed to successfully represent the astrometric observations of comets Halley, d'Arrest, Kopff, Brooks 2, Grigg-Skjellerup, Giacobini-Zinner, Churyumov-Gerasimenko and Tempel 2. This new model allows the water vaporization curve to peak on either side of perihelion, thus introducing a nongravitational force via an asymmetric radial force, rather than through a symmetric transverse effect that the old model requires. Results suggest that the optimum location of the water vaporization peak, required for a comet's nongravitational forces, aligns with the location of its visual light curve peak.

An existing orbit for the close Earth approaching asteroid 3908 (1980 PA) was improved using optical astrometric data. This improved orbit allowed successful radar observations at the Arecibo radar facility. The range and Doppler observations from Arecibo were, in turn, used to further improve the asteroid's orbit for subsequent radar observation at the Goldstone facility.

Accurate ephemerides provided by this task allowed successful radar observations of Phobos, the Galilean satellites, Mercury, Mars, and Saturn as well as allowing successful optical observations of a dozen comets and asteroids.

c. Anticipated Accomplishments: The physical ramifications of the new nongravitational force model will be assessed with respect to the orientation and time history of the spin poles for various cometary nuclei. The ongoing efforts to export accurate optical and radar ephemerides for comets, asteroids and planets, will continue.

d. Summary Bibliography:

Ostro, S.J., Yeomans, D.K., Chodas, P.W., Goldstein, R.M., Jurgens, R.F., and Thompson, T.W. Radar observations of asteroid 1986 JK. *Icarus*, 1989 (in press).

Ostro, S.J., Jurgens, R.F., Yeomans, D.K., Standish, E.M., Greiner, W., and the DSN Radar Astronomy Unit. Radar detection of Phobos. Submitted to *Nature*, January 1989.

H I G H L I G H T S
O F
R E C E N T A C C O M P L I S H M E N T S
I N
P L A N E T A R Y A S T R O N O M Y

Using simultaneous observations from NASA's Infrared Telescope Facility and the University of Hawaii's adjacent 88-inch telescope, M. F. A'Hearn (University of Maryland), H. Campins (Planetary Science Institute), D. G. Schleicher (Lowell Observatory), and R. L. Millis (Lowell Observatory) showed that the nucleus of Comet P/Tempel 2 is nearly a twin of the nucleus of the much brighter and better known Comet P/Halley. It is roughly the same size and shape (8 x 8 x 16 km) and just as dark (reflectivity 2%). It is, however, much redder than P/Halley's nucleus and gas is being released from a much smaller fraction of the surface (~ 1% instead of 15 - 30%) which is one of the two major reasons why the comet as a whole is much fainter than Comet P/Halley (the other reason is its greater distance from the sun). These observations provide confirmation of theories which predict that mantles can grow on cometary nuclei until they eventually choke off evaporation, leaving the nucleus looking like an asteroid. These extinct cometary nuclei may represent a significant fraction of the asteroids that come close to Earth.

The Soviet Union has recognised the importance of Phobos and Deimos by launching its most ambitious unmanned space probe to Phobos. This spacecraft has the primary mission of determining the water content of Phobos. By coincidence, at the same time Mars passed through the most favorable opposition for Earth-based observations in the remainder of this century, providing a rare opportunity for ground-based studies of the Mars satellites. An intensive program of telescopic studies was carried out in September-October 1988 by planetary scientists at the University of Hawaii, using the facilities of the Mauna Kea Observatory. Part of this program involved IR spectral studies of the outer satellite Deimos, which will not be visited by the Soviets due to the loss of one of their two spacecraft. Deimos was found to have a red reflectance curve in the 1.2-2.2 micron region. This is typical of the P-class asteroids found in the outer asteroid belt, rather than the C-class asteroids like Ceres which have been the traditional analogs for Phobos and Deimos. P asteroids are found just inside the gap between the main asteroid belt and the Trojan asteroids, suggesting that the Phobos/Deimos parent body was delivered to Mars during the cleaning out of this region. The reddening of P-class asteroids is conventionally attributed to an increased abundance of complex organic polymers over that in C-class asteroids and the carbonaceous meteorites. In addition, the amount of water in Deimos was measured directly by means of the bound-water band at 3 microns, which has been detected in many dark asteroids. The observations indicate that Deimos is *much less hydrated* than the "average" main-belt C-type asteroid, and probably completely dry. These results indicate that Deimos, and possibly Phobos, does not incorporate significant amounts of hydrated silicates which could serve as a source of water or hydrogen for future space missions; however, the large amounts of hydrocarbon compounds inferred to be present could serve as an alternate source of light elements for life support or propulsion.

Once every 124 years, nature provides earth-bound astronomers with the opportunity to observe occultation and transit phenomena between Pluto and its satellite, Charon. Ground-based observations of these events will allow physical parameters for the Pluto-Charon system to be derived which are unlikely to be improved upon until *in situ* spacecraft observations are obtained. The NASA Planetary Astronomy program supports photometry observations from McDonald Observatory (Fort Davis, TX), a critical location in an international Pluto Campaign network. Knowledge of the diameters, masses, densities, and compositions derived from these observations will augment our understanding of Pluto's origin and its context within the problem of solar system formation.

During 1988, new photometric observations in B and V filters were obtained during 6 transit events and 2 occultation events using the McDonald Observatory 2.1- and 2.7-m telescopes. Attempts for 2 additional events were completely clouded out. During this time, Charon and its shadow were passing across the equatorial region of Pluto. An analysis of the hemispherical color distribution on Pluto and Charon was completed during 1988, with results showing the two bodies have very different, but uniform colors. Observations of Pluto-Charon mutual events are continuing through 1989 and 1990 and a detailed analysis is underway to derive "maps" of the surface albedo distributions on Pluto and Charon. A preliminary analysis of the 1985-1988 data suggests direct evidence for relatively bright polar caps on Pluto.

The close approach of Venus to the earth in the summer of 1988 provided an opportunity to image the surface with the Arecibo 12.6cm wavelength radar. Improvements in data acquisition hardware and analysis software since the last mapping effort in 1983 enabled us to obtain data which will provide images in two polarizations at resolutions down to 1.3 km over large areas of the northern and southern hemispheres. The initial data reduction has provided images in the latitude range 12°N to 45°N stretching over 10,000 km of longitude from Beta Regio in the west to Eüsila Regio in the east. The surface in this region appears to be of mainly volcanic origin with only isolated areas of what resembles older, Tessera-like terrain. These images also overlap the southern edge of the coverage obtained from the Venera 15/16 spacecraft. A comparison of the two data sets highlights the differences in radar images taken at different incidence angles, 7° to 13° for Venera and 35° to 50° for Arecibo.

The stellar occultation by Pluto on June 9, 1988 was observed both with the KAO and from ground-based sites. The airborne occultation light curve, which probed two regions on the sunrise limb separated by about 2000 km, reveals a clear upper atmosphere that overlies an extinction layer with an abrupt upper boundary. The observations demonstrate that the extinction layer extends along the portion of the sunrise limb bounded by the immersion and emersion regions, as well as along the corresponding portion of the sunset limb on the opposite side of the planet. Hence, it is likely that the extinction layer may surround the entire planet. Fits of a model atmosphere to the immersion and emersion light curves show no significant differences in the derived atmospheric structure. A preliminary geometrical solution, based on three occultation chords yields a half-light radius of 1214 ± 20 km. At this level, the mean scale height derived from the model fits to the airborne data is 59.7 ± 1.5 km. The corresponding ratio of temperature to mean molecular weight is 4.2 ± 0.4 °K/amu, with the principal source of error arising from the uncertainty in the mass of Pluto. The extinction layer, whose upper boundary lies 25 km below the half-light level, has a minimum thickness of 46 km, a minimum vertical optical depth of 0.19, and a scale height of 33.4 ± 6.9 km. For a pure methane atmosphere, our results imply (for the clear atmosphere at the half-light level) a temperature of 67 ± 6 °K, a number density of 8.3×10^{13} cm⁻³, and a pressure of 0.78 mbar. Our occultation data is also consistent with a predominantly nitrogen atmosphere (such as that of Titan), in which case the temperature would be 117 ± 11 °K. The substantially smaller scale height of the extinction layer may arise from properties of "particles" causing the extinction or may indicate a lower temperature in this region. Since our analysis indicates that the extinction layer is optically thick at the limb of Pluto, determinations of Pluto's radius by methods that use reflected light, such as speckle interferometry and observations of the mutual events, give results that refer to the *visible disk* of Pluto and not to the planet's solid surface. Unit optical depth of the extinction layer (observed along the line of sight) lies at 1174 ± 20 km, a level consistent with the radius of Pluto derived from the mutual events (1142 ± 21 km). The mutual event radius is also consistent with the deepest level probed by the occultation: it lies at a radius of 1143 ± 20 km, which represents an upper limit on the surface radius. For a pure methane atmosphere, a surface pressure as low as 3 mbar (the vapor pressure of methane at 50 °K) would be consistent with the occultation data.

Reflectance spectra of the Trojan asteroids and their location at the L4 and L5 Lagrangian points of Jupiter, far beyond the main asteroid belt, indicate that these asteroids probably differ significantly in composition and collisional evolution from main belt asteroids. Systematic surveys of rotation parameters--frequency, lightcurve amplitude, and pole orientation--can yield information about both initial formation processes and subsequent collisional modification. Because of their great solar distance and their corresponding faintness, knowledge of the rotation properties of the Trojan asteroids was scant until just a few years ago. Charge-coupled device detectors and 1-2-meter class telescopes are being used to survey systematically the rotation properties of the Trojan asteroids. We are also using the Curtis Schmidt telescope of the Cerro Tololo Interamerican Observatory to discover and determine orbits for new L5 Trojan asteroids.

The lightcurve amplitudes of the Trojan asteroids are significantly larger, on average, than those of main belt asteroids (French, 1987; Hartmann *et al.*, 1987, 1988; French *et al.*, 1989). Since Trojans undergo fewer and less energetic collisions with other asteroids because of their lower number densities and orbital velocities, this discrepancy could well be due to differences in collisional evolution between main belt and Trojan asteroids. For the main belt objects, knowledge of the distribution of rotation frequency and lightcurve amplitude with size is leading to an understanding of the physical processes which dominate large and small asteroid rotation. Dermott *et al.* (1984) showed that an excess of slow rotators at about ~ 120 km is present; both larger and smaller asteroids tend to rotate faster. The effect is seen for the three dominant compositional types among main belt asteroids, with the minimum in the frequency-diameter curve occurring at slightly different diameters for C, S, and M objects. We are establishing the data base needed to make such a study for Trojan asteroids, where P and D types predominate.

Once the lightcurve properties are known, the asteroid's phase curve gives information on the surface texture. Earlier studies (French, 1987) of the Trojan 1173 Anchises show no opposition effect at phase angles less than 5° , unlike the behavior which would be expected for other dark asteroids. Further phase curve studies are planned, including simultaneous visible-infrared photometry to determine whether the infrared beaming properties of Trojans are unusual as well.

The Schmidt survey being done at CTIO under this proposal is part of a collaborative effort with E. and C. Shoemaker using the 18" Palomar Schmidt and E. Bowell, S. J. Bus, and K. Russell using the 48" UK Schmidt. The Shoemakers will survey the entire L5 region down to 18th magnitude, while the UK Schmidt will take two 6° fields centered on L5 for accurate statistics down to 23rd magnitude. Our CTIO study will provide both statistical information and accurate orbits. 60-day orbital arcs were obtained in 1988; this will be sufficient to recover the asteroids in 1989 and thus enable their permanent cataloging and numbering. Time will be requested from CTIO for physical studies of several new faint Trojans in late 1989.

We are also monitoring the absolute brightness and lightcurve variation of 2060 Chiron during our observing runs. The apparent brightening of the object in 1987 and 1988 (Tholen *et al.*, 1988) suggests that it may be undergoing some cometary-type outbursts. Our October observations showed a lightcurve amplitude less than half of that observed by Bus *et al.* in 1986, suggesting further that a coma may be developing around the object, masking the light variations due to the rotation of the solid body. Further observations are planned as Chiron continues to approach perihelion.

New techniques of surveying for comets and asteroids are being developed with charge-coupled devices (CCD) at the University of Arizona and, in a cooperative program, at the Indian Institute of Astrophysics.

A 2048 x 2048 CCD, the largest in the world, has been installed at the Spacewatch Telescope, which is the 91-cm Newtonian reflector of the Steward Observatory on Kitt Peak, Arizona. At the Kavalur Observatory in India a dedicated 127-cm CCD-scanning telescope is being designed for this work while other preparations and the funding are coming along nicely.

SILICATE EMISSION IN COMET BRADFIELD (1987s) S. HANNER

A 10-micron CVF spectrum of Comet Bradfield (1987s) was obtained at the NASA Infrared Telescope Facility on 13 January, 1988 when the comet was at $r = 1.45$ AU post-perihelion. The spectrum, divided by the interpolated continuum, is shown in the Figure. A peak at 11.3 microns is evident, similar to that first detected in Comet Halley, and identified as crystalline olivine (Bregman et al A & A 187, 616, 1987; Campins & Ryan ApJ, in press, 1989).

Our result is significant in showing that Bradfield, a long-period comet, also contained small crystalline olivine grains. Silicate grains in the interstellar medium are thought to be amorphous in their structure, because no distinct peaks are seen in the broad 10 micron silicate feature.

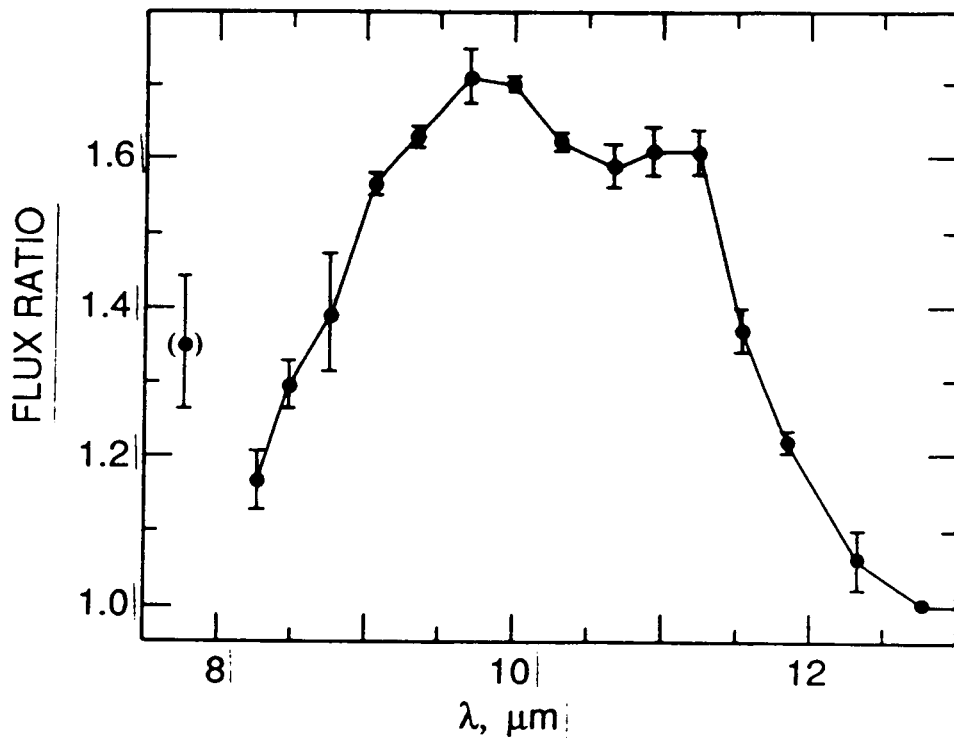


Figure 1. Spectrum of Comet Bradfield (1987s) taken with a 2% circular variable filter at the NASA Infrared Telescope Facility, Mauna Kea. Observed fluxes were divided by the continuum and normalized at 12.81 μm.

THE PALOMAR PLANET-CROSSING ASTEROID SURVEY (PCAS) . E.F. HELIN

Over 200 asteroids have been discovered and reported since January 1988 during the PCAS program conducted at Palomar Observatory using the 0.46 m Schmidt Telescope. Noteworthy among these discoveries are the following: Apollo asteroid 1988 EG, Amor asteroid 1988 PA, Apollo 1989 AC (independent), 9 Mars crossers, 21 high-inclination inner-belt asteroids: 9 Hungarias, 10 Phocaeas, 1988 EO, and 1988 RH, unusual objects with inclinations greater than 30 degrees with large semi-major axes as well, placing them in isolated regions of phase space. Distant short-period comet 1989b was discovered which is dynamically intriguing. With a period of 8.12 years and a low inclination and eccentricity, it made a close pass to Jupiter in 1983 which may be responsible for its present orbit. It has a dynamically short lifetime.

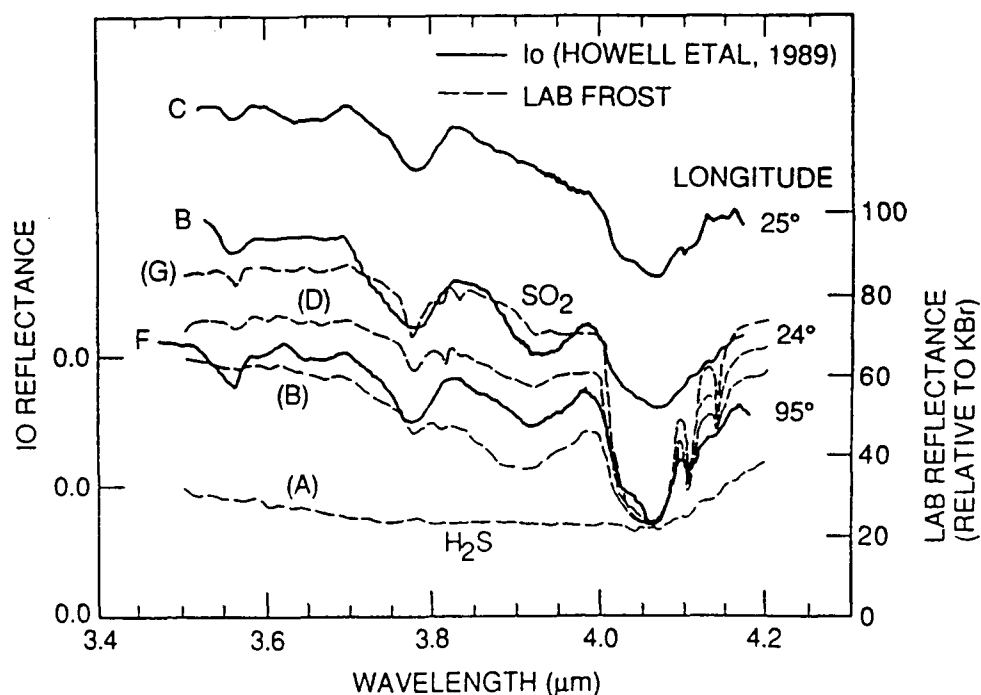
INFRARED SPECKLE INTERFEROMETRY AND SPECTROSCOPY OF IO

R.R. HOWELL

Comparison of "anomalous" Io observations with recent laboratory spectra suggests that H_2S frost may be present on the satellite. The Io spectra are considered anomalous because they differ significantly in the 3.9 micron region from spectra obtained at other times. Three such anomalous spectra (heavy lines labeled B, C, and F) are shown below. The most reliable one is F, as it is the average of 4 separate scans through the wavelength interval. The broad feature at 3.915 microns is absent or at least much weaker in other Io spectra, and is not present in SO_2 frost. Nash recognized that it resembled a feature occurring when H_2S was condensed with SO_2 .

Unlike spectrum F, spectra B and C were taken about 40 minutes after an eclipse reappearance. They also seem to show features in this region. They are single scans through the wavelength region, and could possibly be affected by undetected problems such as clouds or mis-centering. However, if real the feature in B could be explained by condensation of H_2S frost during eclipse. The explanation for the elevated values in C is more puzzling.

The presence of H_2S frost, and an accompanying H_2S atmosphere, is being investigated by others as a possible explanation of the dark polar caps, and as a means of limiting the flow of SO_2 gas towards the poles.



Sprague (Tyler), Kozlowski, and Hunten have observed sodium D emission off the subsolar limb of the Moon, confirming the slightly earlier but independent discovery by Morgan and Potter. The latter workers also observed an even smaller quantity of potassium. The sodium number density is only 60 atoms cm^{-3} , only 1/400 as much as on Mercury. Tyler has successfully modeled this difference as being due to much more rapid diffusion of alkali atoms through the regolith at the higher temperature of Mercury. This relatively easy diffusion must occur along grain boundaries; it is far slower within mineral lattices.

THE REFLECTION OF LIGHT FROM ROUGH PLANETARY AND
SATELLITE SURFACES W.M. IRVINE

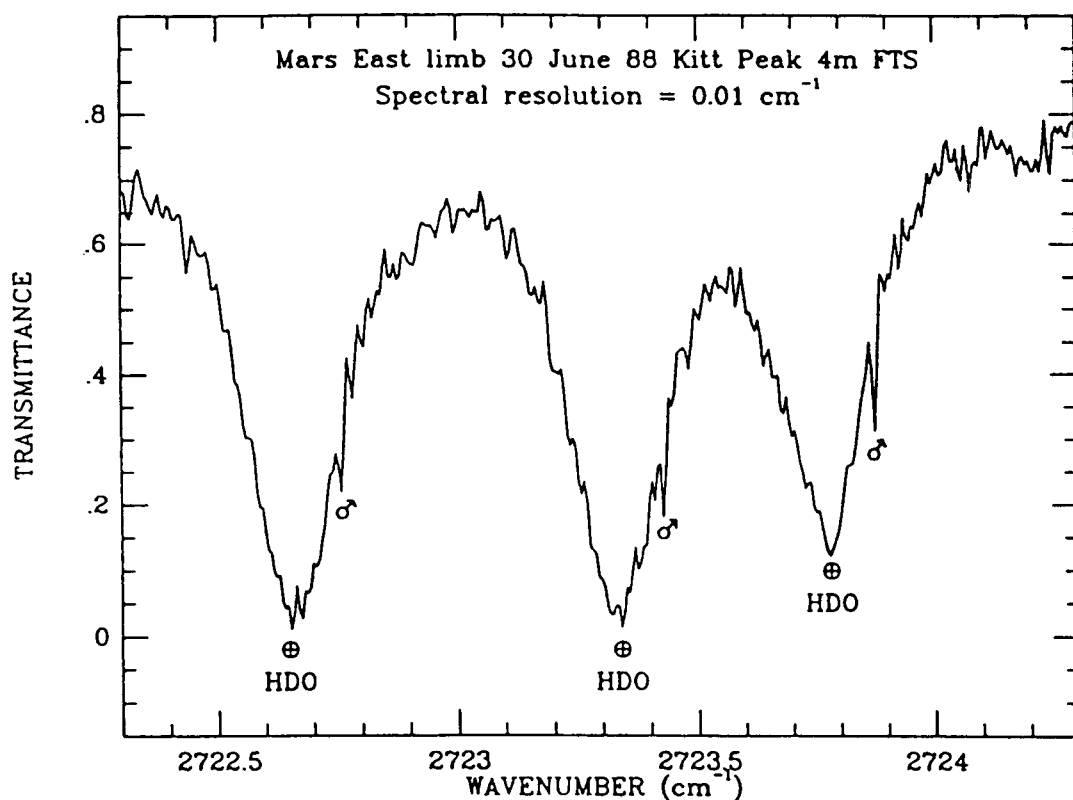
Traditionally, light scattering by particles in planetary science applications has been approximated by a theory which strictly applies only to homeogeneous spheres. This is obviously not strictly appropriate for typical aerosols and surface particles. In order to more exactly replicate the pattern of light scattering and polarization produced by such particles, calculations have been carried out by Monte Carlo simulation for "rough" particles formed by random deformations of spheres and for various categories of crystals. Among the applications it appears that the recently discovered narrow-intensity spike observed in direct backward scattering from the surfaces of icy satellites may be explainable in terms of presence of a small proportion of retroreflective crystals.

STUDY OF MICROWAVE EMISSION BY THE OH RADICAL IN
RECENT COMETS W.M. IRVINE

Graduate student Lowell Tacconi-Garman has recently completed his Ph.D. dissertation on the analysis of radio OH line profiles of P/Halley and other comets taken by our group during the International Halley Watch campaign. Such observations are especially sensitive to the kinematics of molecules in the coma because they resolve the doppler broadened line shape of the emission, and this particular set of data represents the most complete and accurate samplings of coma velocities yet obtained in a reasonably broad cross section of cometary production rates and heliocentric distances. In all, a total of 16 line profiles from 5 comets have been analyzed to obtain the velocities and distribution of molecules in the coma.

The behavior of the parent outflow velocities derived from the observations is, in many ways, consistent with the expectations of theoretical models. That is, the outflow speed increases as the comet approaches the sun in a manner consistent with the enhanced heating that is expected there. In addition, evidence is found for an increase in the outflow speed with increasing production rate at any particular heliocentric distance, which is another feature of most thermodynamic models of the coma. What is not reproduced, however, is the magnitude of the velocity at moderate heliocentric distances and production rates. In general, the derived velocity falls 0.2-0.5 km/sec below the predicted values under these conditions. The reason for this discrepancy remains a mystery and will be the subject of future research.

HDO was observed on Mars during June 1988 using the 4-meter telescope and FTS at Kitt Peak. The figure shows a portion of the Martian spectrum near 3.7 microns wavelength. The narrow Martian HDO lines are Doppler-shifted by 10 km/sec from the strong telluric lines. HDO was detected at two locations on the disk of Mars, thus demonstrating the feasibility of measuring its spatial variation.



Comet SW1 is famous for its occasional photometric outbursts, during which its total magnitude may rise from $m \sim 18 - 19$ (in "quiescence") to $m \sim 12 - 13$ (in outburst). The outbursts consist of sudden ejections of dust particles, perhaps driven by an intermittently active volatile (CO and CO₂ are frequently suggested candidates). Comet SW1 is important as the archetypical outbursting comet. While outbursts are suspected to occur in most or all comets, they are best observed and best characterized in SW1.

We have found that SW1 displays a second mode of activity, physically distinct from the well known outbursts. Time resolved CCD images in the 1987 and 1988 observing intervals reveal an extensive and persistent coma, upon which the photometric outbursts are super-imposed. This continuous or "quiescent coma" has a total magnitude $m < 13.5$, and is produced by dust particles ejected from the nucleus at an approximate but steady rate $dm / dt \sim 100 \text{ kg / s}$. Surprisingly, this rate of mass loss can be supplied by equilibrium sublimation of crystalline water ice from only a few percent of the surface area of the nucleus of SW1. We believe that the quiescent coma is analogous to the persistent coma first observed in Comet Halley at a similar heliocentric distance ($R \sim 6 \text{ AU}$). The quiescent coma in SW1 may be modulated by orbital variations in R ; the present data were taken near perihelion at $R = 5.7 \text{ AU}$.

The identification of the quiescent coma may throw light on the mechanism responsible for the outbursts in SW1 and other comets. The steady sublimation implied by the quiescent coma will cause sub-surface ices to be exhumed from the nucleus at a rate $1 - 10 \text{ mm / year}$ (depending on the unknown regolith density). The interplay between equilibrium sublimation of the crystalline water ice matrix and occasional exposure of sub-surface volatiles (or amorphous ices) provides a qualitative explanation for both the quiescent and the outburst components of the coma, respectively. The extreme photometric properties of SW1 may be understood as an artifact of the unusual orbit. The nearly circular orbit at $R \sim 6 \text{ AU}$ places SW1 at the outer edge of the crystalline water ice sublimation zone. At larger R , the crystalline water ice would not sublimate significantly, while at smaller distances, the equilibrium water sublimation would overwhelm sporadic mass loss produced in typical outbursts. Future observations may provide invaluable empirical constraints on the physical nature of steady and non - steady state activity in comets.

In addition to the quiescent coma, we find a quasi - periodic modulation in the central light of the comet. The photometric observations observed there show a characteristic timescale close to but longer than the 5 day period advanced by Whipple using independent data. It is likely that the nucleus of SW1 is detected in our data.

SYNCHROTRON EMISSION FROM JUPITER SHOWS CORRELATION
WITH SOLAR WIND M.J. KLEIN

Since April 1971, the antennas of the NASA Deep Space Network have been used to measure Jupiter's decimetric flux density several times a month at a wavelength of 13.1 cm (2295 GHz). This program was initiated both to study the time variable synchrotron emission, and to help bridge the gaps between the in-situ Pioneer and Voyager measurements of the Jovian-Van Allen radiation belts, and anticipated measurements from Galileo in the 1990's. The DSN data, combined with pre-1971 data, provide a total record of time variations for more than two solar cycles. Variability on time scales of a few years and longer are clearly present in the data.

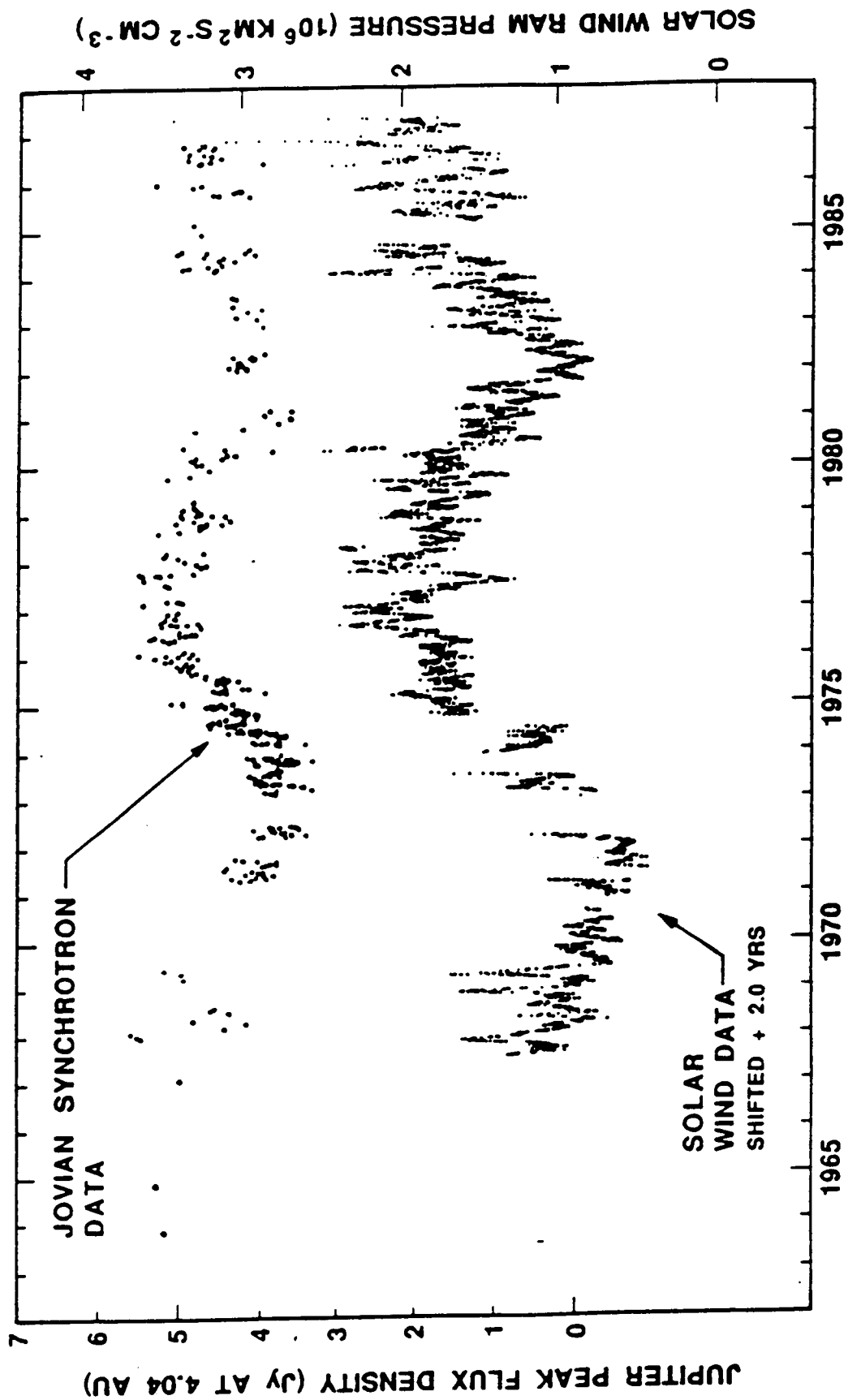
Time variability of the Jovian synchrotron emission is related to the sources and losses of the high energy electrons in the Van Allen Belts. At present, these processes are poorly understood. One goal of our research was to investigate the possibility that the variations of synchrotron emission are correlated with any of the measured solar wind parameters. Utilizing the large amount of solar wind data that is now available for various spacecraft in near-Earth orbit, we searched for and found correlations between a number of solar wind parameters. Significant non-zero correlation coefficients appear to be associated with solar wind ram pressure, ion density, thermal pressure, flow velocity, momentum, and ion temperature. The highest correlation coefficients were obtained for solar wind ram pressure and thermal pressure. The delay time for the correlation is about 2 years.

The implication of these results, if substantiated by further measurements, is that the solar wind is influencing the supply and/or loss of electrons to Jupiter's inner magnetosphere.

Michael J. Klein
Samuel Gulkis
Scott J. Bolton

Sponsor. OSSA

Opposite page. Measurements of the Jovian synchrotron emission from 1965-1987 are shown in the top of the Figure. The solar wind ram pressure data, shifted forward 2 years in time are shown on the bottom of the Figure. The similarity between the two data sets are obvious.



Planetary research efforts under this task are quite diverse, and include cometary studies, high spectral resolution observations of planetary atmospheres, measurements relevant to spectroscopic planetary detection, and imaging using infrared array detectors. We here discuss two selected highlights from this broad array of research.

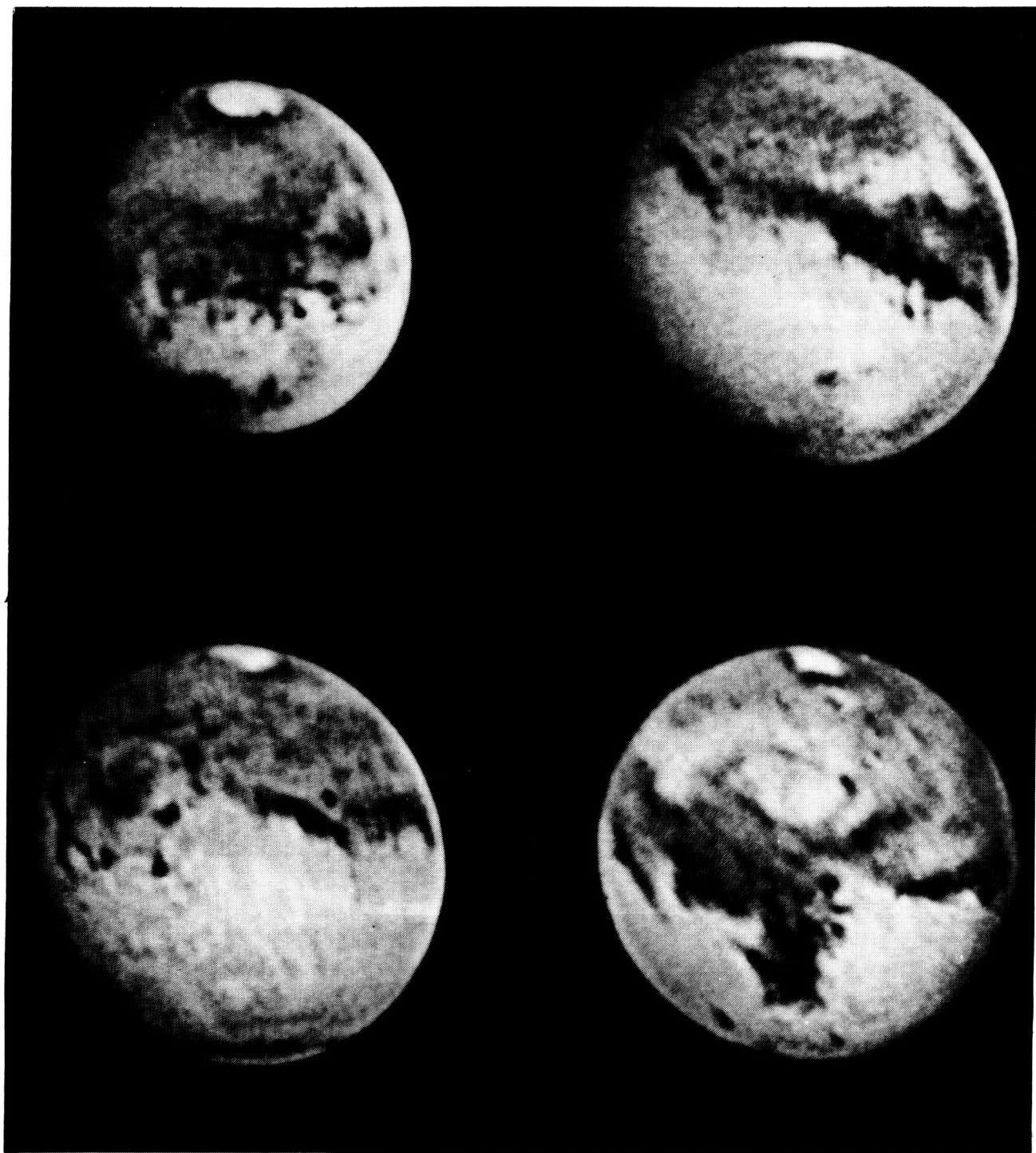
Jovian Thermal Waves: The advent of sensitive array detectors for the thermal infrared spectral region opens up new avenues of research in planetary astronomy. One particularly interesting problem involves the detection of wave motions on the Jovian planets by sensing the infrared brightness temperature fluctuations which result from the wave-induced temperature perturbations. In November 1987 Jupiter was observed using a linear array of 20 detectors to sense brightness temperature fluctuations as a function of Jovian longitude. The original purpose of these observations was to search for p-mode oscillations, such as are seen on the Sun. Negative results were obtained as concerns p-modes, but the data unexpectedly revealed the presence of a very low frequency thermal wave structure at low Jovian latitudes (equator and 20° N). This wave structure has an amplitude of ~ 0.3 Kelvins in $8\text{--}13\text{ }\mu\text{m}$ brightness temperature, shows ~ 10 wavelengths per planetary circumference, but exhibits no obvious relation to visible cloud features. It has the same amplitude and spatial scale as the "slowly moving thermal features," recently discovered in the Voyager IRIS data by Magalhaes et al. (1989, *Nature* 337, 444), and which these authors attribute to a "deeply-rooted fluid dynamical regime beneath the surface meteorology". Our observations of the thermal wave structure will be reported in in The Astrophysical Journal, August 1, 1989.

Martian D/H Ratio: The knowledge of Martian D/H ratio and thus, the degree of deuterium enrichment in the present atmosphere plus regolith system, is seminal in the understanding of Mars' atmospheric evolution. Until recently deuterium had never been detected in the Martian atmosphere. Recent ground based observations by Owen et al. (1988, *Science*, 240, 1767) inspired Yung et al. (Icarus, in press) to develop a photochemical model for HD0 and H_2O in the Martian Atmosphere. To provide data to better constrain this photochemical model, simultaneous measurements of HD0 and H_2O in the Martian atmosphere were acquired using the Fourier Transform Spectrometer on NASA's Kuiper Airborne Observatory (KAO). We observed the whole disk of Mars on 5 August 1988. The strong ν_3 bands of HD0 and H_2O at $2.65\text{ }\mu\text{m}$ were detected in absorption against the continuum of reflected solar radiation. This spectral region is totally obscured by telluric H_2O at all ground-based observatories, but at aircraft altitudes this important window permits the detection of water in planetary atmospheres and comets. Our retrieved value for the line of sight Martian water abundance was, $\eta_a(\text{H}_2\text{O}) = 39.5 \pm 0.4$ pr μm . Assuming an airmass of 4, appropriate for whole disk measurements, the one way column abundance of 9.9 pr μm is consistent with that observed by Viking at the same season. The retrieved HD0 abundance was $\eta_a(\text{HD0}) = (6.10 \pm 0.13) \times 10^{-2}$ pr μm . The corresponding D/H ratio is $(7.73 \pm 0.17) \times 10^{-4}$. This is 5.15 ± 0.2 times the terrestrial value (including systematic errors). Our measurements will help to constrain the size of the exchangeable water inventory on Mars to a value near 20 cm, if the Yung et al. formalism is correct.

HIGH RESOLUTION GROUND BASED IMAGES OF MARS S. LARSON

New high resolution groundbased images of Mars and Jupiter have been taken with the 1.5-m Catalina reflector during the favorable mars apparition in 1988. By using short exposures permitted by the CCD, a pixel size of 0.12 arcsec and digital high-pass filtering, it is possible to resolve albedo features on the surface only 100 km across. These pictures show virtually all of the detail that can be seen through the telescope by the eye. Images of Mars were obtained through a series of filters from 360-100nm to aid study of atmospheric features and geologic domains. Similar images of Jupiter show the small scale structure that changes on a daily basis. Future application of CCD imagery and image processing such as this will permit monitoring changes in planetary atmospheres from the ground as never before.

The red-light CCD images on page 160 were taken by S. Larson (Lunar and Planetary Laboratory) and G. Rosenbaum (Steward Observatory) with the University of Arizona 1.54 m Catalina Station telescope. Exposure times were all 1.0 sec and are reproduced at the same angular scale. The images have undergone digital high-pass filtering with the help of C. Slaughter and W. Schempp (Photometrics Ltd.).



MARS 1988

August 18.4632 UT ($\lambda=39^\circ$)

September 9.4439 UT ($\lambda=193^\circ$)

September 10.2856 UT ($\lambda=128^\circ$)

October 3.3278 UT ($\lambda=300^\circ$)

We now have broadband and narrowband spectrophotometry (1.2 to 3.5 μ m) of 30 low albedo asteroids. This is an extension of our original work and now includes F-, P-, D-, and T-class asteroids. If these asteroids are truly more primitive than the Cs, then we may expect to see more surface volatiles and thus deeper bands at 3 μ m indicative of the presence of hydrated silicates. Although it has been thought previously that these outer belt and Trojan asteroids are more "primitive" than the Cs and thus should show a larger volatile content (i.e., hydrated silicates and organics), we find that most of them do not show the spectral signature of hydrated silicates, silicates and organic material (Figs. 1 and 2).

Our observations appear to show that water (in the form of hydrated silicates) is absent on the surfaces of outer-belt and Trojan asteroids. However, we do appear to see some features for which we have no identification.

The most likely implication of our results seem to be that while many of the C asteroids closer to the Sun contain hydrous minerals, the asteroids in the colder, more remote regions of the asteroid belt do not. This conclusion appears to conflict with what might be predicted by a straightforward application of the equilibrium condensation theory.

Figure 1

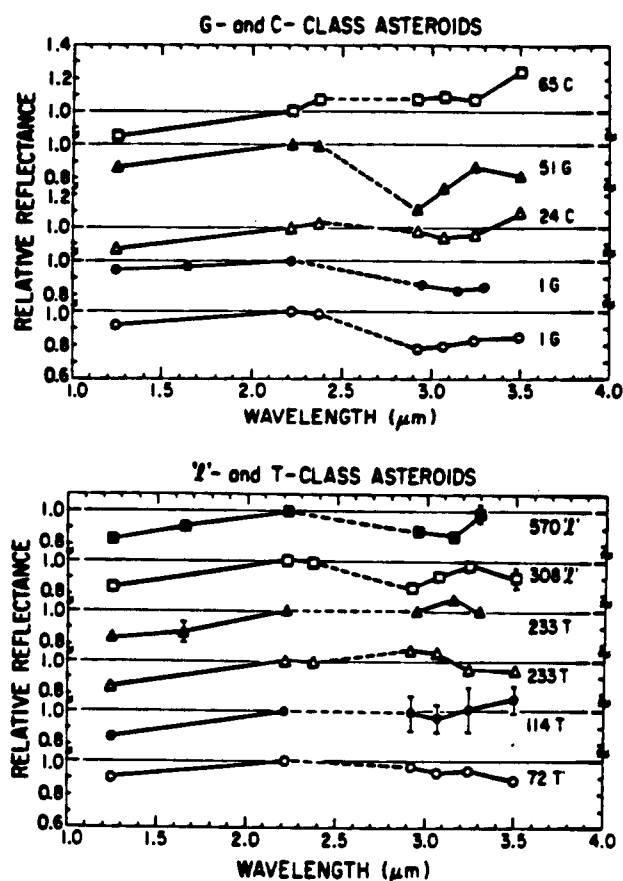
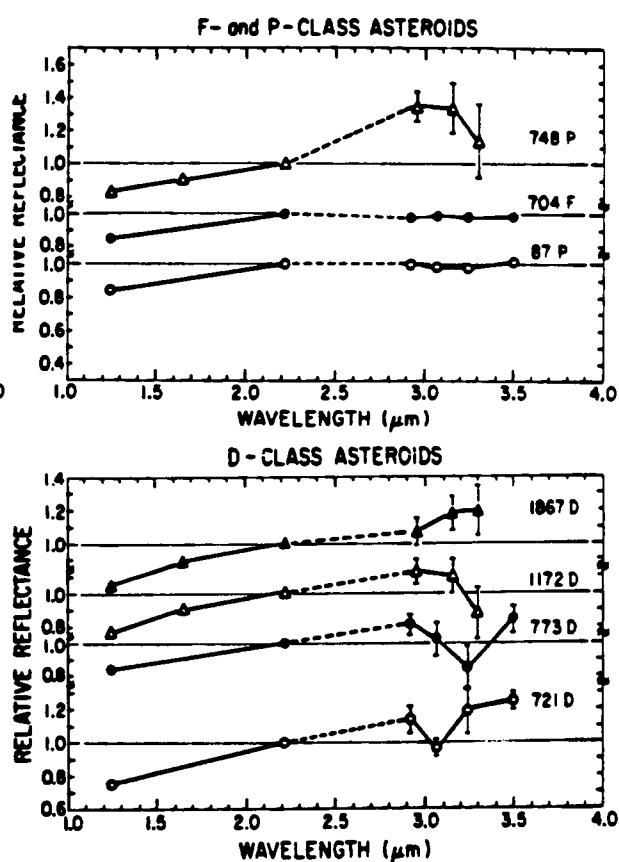


Figure 2



ASTROMETRIC OBSERVATIONS OF COMETS AND ASTEROIDS
AND SUBSEQUENT ORBITAL INVESTIGATIONS R.E. McCrosky

Following our discovery that two of the comets we observed, 1988e and 1988g, had practically identical orbits (but were separated by 76 days), we made a detailed study of the relationship, suggesting that the two comets separated from each other at their previous perihelion passage, some 13 000 years ago, but that the components were orbiting around each other until the relative nongravitational force on them allowed them to escape from each other, evidently at some rather considerable distance from the sun.

HAZY ATMOSPHERE REVEALED ON PLUTO R.L. MILLIS

On June 9, 1988 Pluto passed in front of a distant star known to astronomers as P8. This rare occultation, the first ever to be seen involving Pluto, was recorded at 8 sites in Australia, New Zealand, and the South Pacific. Lowell Observatory astronomers funded under NASA Grant NSG-7603 joined forces with colleagues at Lick Observatory and the U.S. Naval Observatory to predict where on the surface of the Earth this elusive event would be observable. Portable groundbased equipment from Lowell Observatory and the Kuiper Airborne Observatory were deployed on the basis of these predictions and both succeeded in observing the occultation. The observations confirmed with certainty the existence of an extended, but tenuous atmosphere on Pluto. The results are consistent with the atmosphere being composed of pure methane, but other possible constituents cannot be ruled out. The occultation observations also revealed a planet-wide haze layer in Pluto's atmosphere. While the haze is partially transparent near the center of the planet, it is apparently dense enough to obscure Pluto's limb. As a consequence, previous measurements of Pluto's diameter may not refer to the body's solid surface. Further analysis of the astrometric measurements used to predict the June 9 occultation, has produced evidence that Pluto is less massive than previously believed.

AN ADVANCE IN KNOWLEDGE OF COMETS R.L. NEWBURN, JR.

The "icy conglomerate" model of comets was developed by Whipple and published in 1950. In 1952 Delsemme and Swings introduced the idea that most cometary volatiles were trapped in the molecular lattice of the major cometary ice, ordinary water ice, and therefore were released at much higher temperature than if frozen free on the comet nucleus. Such a "physical" compound, called a clathrate, offered an explanation of why comets usually appear to "turn on" when they reach the temperature at which water sublimates. The only major addition to this general picture during the next 34 years was the 1971 idea of Delsemme and Miller that comets might possess a halo of icy grains near the nucleus, creating an extended source of volatiles.

In 1986 A'Hearn and coworkers reported the existence of jets of CN and C₂ in Comet Halley that were distinct and separated from the well-known dust jets. He suggested they originated from the very small particles made up of C, H, O, and N discovered by Giotto and VEGA, particles too small to scatter light efficiently so they could be seen visually. Combi soon found that jets of gas could persist from the surface, if collimated by a deep throat.

An analysis of dust and gas data from 25 comets observed between 1980 and 1986 has just been published (Feb. 1989) by Newburn and Spinrad. These data show that comets with little or no dust still have some CN, apparently coming from a parent molecule (probably HCN) originating on the surface. They also show a strong correlation between dust and CN, dustier comets having much more CN than those with little or no dust. This clearly implies that part of the CN does originate during the fragmentation and/or volatilization of dust.

Astronomers Glenn Orton and Jim Friedson at the Jet Propulsion Laboratory and John Caldwell at York University (Ontario, Canada) have made images of Jupiter's temperature field in the stratosphere, using a raster-scanning technique at NASA's Infrared Telescope Facility atop Mauna Kea on the island of Hawaii. The images show infrared (heat) radiation at 7.8 microns wavelength emitted by methane molecules in Jupiter's atmosphere.

Images made by this group in the past have shown 2 bright axisymmetric bands at about 20 degrees latitude north and south of the equator, and often a third band at the equator. Other bright features have been detected as "hot spots" near the poles and are associated with the magnetic field.

Images taken on December 9 and 10, 1987, when the center of the planet was about 312 degrees W in the middle of the observation (in the longitude system rotating with the planetary interior) reveals for the first time the presence of elongated and arc-like features and bright spots, near 25 degrees N and 30 degrees S latitude, stretching across a wide range of latitudes and longitudes. These features, over the two days of these observations, appear to be stable and fixed in a longitude system which is associated with the internal rotation of the planet. This image also shows that the north mid-latitude bright band has extended poleward to 30 degrees north latitude with a broader component stretching as far south as 7 degrees N latitude. Other faint bands are detectable at 50 degrees N and 35 degrees S which have not been seen previously.

Later, in September of 1988, prominent non-axisymmetric features were seen associated with the northern bright band. An elongated feature which is about 15,000 km in length is several degrees warmer than its surroundings and stretches from about 30 degrees to 15 degrees N latitude. It appears to be part of a series of features in the northern bright band which are separated by 30 - 40 degrees in longitude. The northern band itself is poleward of its typical position in earlier years, appearing to be at 30 rather than 20 degrees N. Between this night, September 26, and the two nights later, several of the individual features, including the prominent bright feature, appear to be stable and fixed in a longitude system which is associated with the internal rotation of the planet. In general, and particularly near longitudes of about 310 - 330 degrees W, the northern hemisphere appears to be warmer than the southern hemisphere. Other faint bands are detectable in this and other images taken on the same night, e.g. at 10 degrees N, 30 degrees S and 60 degrees S.

The origin of these features and the causes of these time-dependent changes is not understood at this time.

Students associated with this study include: David Anthony (York University), Ian Avruch (Brandeis) and Michael Malcom (Caltech).

Echoes from this near-Earth asteroid were obtained in May and June 1986, three weeks after its discovery, using the Goldstone 3.5-cm-wavelength radar. The asteroid's minimum distance during the observations was less than 0.029 AU, only 11 times further than the Moon and closer than for any other asteroid or comet radar experiment to date. Estimates of echo Doppler frequencies were used in conjunction with the available optical astrometric data to provide refined orbital elements and ephemeris predictions. Using the object's radar cross section, polarization ratio, and echo bandwidth in concert with reported values for its optical magnitude and color indices, we develop a model that postulates a 1-to-2-km object whose shape is not very irregular, with little elongation but some polar flattening; whose rotation period is not more than a few hours longer than 10 hours; and whose surface is characterized by a modest degree of wavelength-scale roughness and by a bulk density within a factor of two of 0.9 g cm^{-3} .

The radar astrometric data are extremely powerful for orbit improvement and probably have secured 1986 JK's optical recovery. At the next close approach (0.12 AU in mid 2000), a search ephemeris based upon all optical and radar data will have a plane-of-sky, solid-angle uncertainty an order of magnitude smaller than for an ephemeris based upon the optical data alone. This experiment demonstrates the value of a rapid response by astronomers using radar and other techniques when an Earth-approaching small body is discovered, and incorporation of radar astrometry in the published orbit estimation sets an important precedent for small bodies. The physical and orbital characteristics of 1986 JK are somewhat comet-like. However, the Earth passes within two lunar distances of the asteroid's orbit, and evidence for recent meteor shower activity associated with this object is lacking.

Echoes from Phobos were obtained during the exceptionally close approach of Mars in Sep/Oct 1988, using the Goldstone 3.5-cm radar telescope. Our observations constitute the first active remote-sensing experiment on a Martian moon, provide the first information about Phobos's near-surface structure and bulk density at cm-to-decimeter scales, and establish a valuable guide for interpreting radar signatures of asteroids and comets. Phobos's radar signature (albedo, polarization ratio, and echo spectral shape) differs from those measured for small, Earth-approaching objects, but resembles signatures of large (≥ 100 -km), C-class asteroids, which dominate the main belt ~ 3 AU from the Sun and are thought to be mineralogically similar to carbonaceous chondrites, our most primitive meteorites. Phobos appears less rough than the Moon at centimeter-to-decimeter scales. The uppermost few decimeters of the satellite's regolith have a mean bulk density within 20% of 2.0 g cm^{-3} and might be much less porous than the lunar regolith. The apparent differences between the surfaces of the Moon and Phobos could reflect pronounced differences in composition or in regolith generating processes.

Phobos and Deimos might be captured asteroids, or perhaps they formed in orbit around Mars from debris that accumulated during the planet's accretion. In either case, they provide our first detailed views of small planetary objects and possibly the most accessible examples of relatively primitive solar system material. These considerations, plus the potential for the satellites to serve as outposts for the human exploration of Mars, argue for detailed characterization of their surfaces and provide the rationale for the current Soviet spacecraft mission to Phobos. The Soviet experiments include radar sounding at 60-cm to 60-m wavelengths as well as close-up visual imaging, but Earthbased radar offers our only source of information about subsurface structure at centimeter-to-decimeter scales, as well as independent constraints on regolith bulk density.

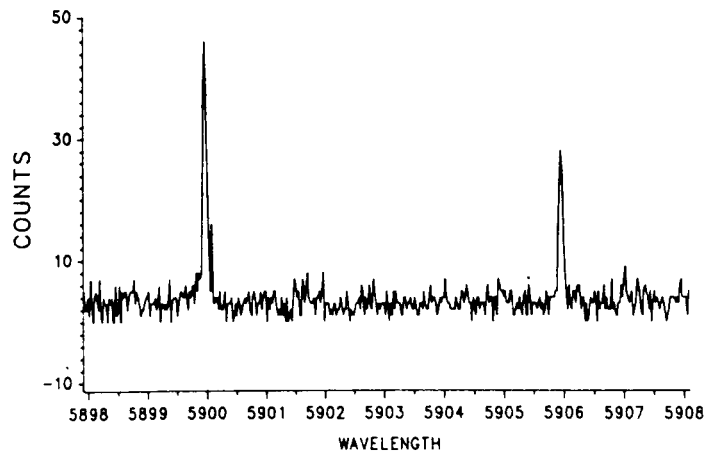
DISCOVERY OF SODIUM AND POTASSIUM VAPOR IN THE LUNAR ATMOSPHERE A.E. POTTER

Sodium vapor is present in the mesosphere of the Earth, in the atmosphere of Mercury, and in the Io torus. Ion sputtering and the effects of meteoroid infall appear to be the principal sources of atmospheric sodium throughout most of the solar system. When illuminated by sunlight the sodium in any of these atmospheres produces two characteristic emission lines, the sodium D lines. The presence of sodium vapor can be detected by spectroscopic measurements of these emission lines.

Recently we discovered a sodium and potassium exosphere about the Moon using this technique (Science, **229**, 675, 1988). Because the Moon is so much closer to us than Mercury or Io it is possible to observe the spatial distribution of sodium above the surface in considerably more detail than is possible in the case of either Mercury or Io. As the sodium exosphere of the Moon is very tenuous, a sodium atom which has just been evolved from the surface of the Moon by meteoritic impact or solar wind sputtering does not usually collide with other atoms in the exosphere. Rather the sodium atom follows a ballistic trajectory ended by collision with the lunar surface. If the newly evolved sodium atoms are very energetic they will reach great heights above the surface of the Moon. Atoms which have suffered many collisions with the surface are in equilibrium with the lunar surface. These "thermalized" atoms have much lower average energies and do not reach great heights above the surface.

If we observe the emission in the sodium D lines at great height above the edge of the Moon, then most of the atoms which are scattering sunlight to form the emission lines are newly evolved sodium. By looking at the emission at great height and determining the number of sodium atoms needed to produce the observed emission we can estimate the rate at which the sodium atoms are evolving from the surface. From such observations (fig. 1), we have been able to determine the rate at which new sodium is produced from the lunar surface (Geophys. Res. Lett., **15**, 1515, 1988). This rate ($\sim 10^5$ atoms $\text{cm}^{-2} \text{ s}^{-1}$) is approximately what we would expect from impact vaporization and charged particle sputtering (Proc. Lun. Plan. Sci. Conf., **19**, 297, 1989). The comparison of the source of new sodium to the lifetime implied by the total amount of sodium present in the exosphere suggests that the effective lifetime of sodium atoms in the lunar exosphere is shorter than the lifetime against photo-ionization. It is possible that the permanently shadowed regions near the lunar poles may be sink for lunar sodium as well.

In the future more observations are expected to provide an even better estimate of the sodium production and to determine the fraction due to each process (impact vaporization and charged particle sputtering). We should then be able to determine the yields of sodium and other materials from real regoliths due to sputtering and to impact vaporization far better than we can from any laboratory experiment.



Emission in the sodium resonance lines 600 km above the bright limb of the Moon.

The analysis and publication of results of our observations of Comet Halley are continuing, partly in collaboration with Karen Magee-Sauer, who is now at Bartol Research Institute in Delaware. A paper on the abundance of NH_2 relative to H_2O in Halley was submitted to Icarus, and another paper on the production rates of $\text{O}(^1\text{D})$, H , and H_2O was also submitted to Icarus.

We are presently preparing a paper on our observations of H_2O^+ emissions from Halley, and we expect to present the preliminary results at the Bamberg symposium in April, 1989. We will also present a paper at that symposium on the results of our very-high-resolution scans of $\text{O}(^1\text{D})$ emission line profiles for Comet Halley.

FABRY-PEROT GROUND-BASED OBSERVATIONS OF THE
JUPITER PLASMA TORUS F. SCHERB

We carried out extensive Fabry-Perot/CCD observations of the Jupiter plasma torus at the McMath solar telescope on Kitt Peak during November-December, 1988. We acquired a large amount of data in the form of spectra and CCD images, and we will be analyzing the data for some time. Part of this program is a Ph.D. thesis for a graduate student. We are also participating in organizing a workshop for Jupiter plasma torus observers, to be held in the summer of 1989.

DETECTION OF FORMALDEHYDE EMISSION FROM COMET
 HALLEY L.E. SNYDER

We used the Very Large Array to detect radio emission from formaldehyde (H_2CO) in Comet Halley (Snyder, Palmer, and de Pater (1989), Astron. J., 97, 246). The H_2CO emission line at 6 cm wavelength (4829.659 MHz rest frequency) had a peak intensity of 2.66 ± 0.78 mJy/beam with a small blueshift of -0.76 ± 0.40 km/s, which is consistent with the anisotropic outgassing of the nucleus in the solar direction found for other cometary species. The data analysis suggests that cometary H_2CO was produced from an extended source in the coma as well as directly from the nucleus and that it was not refrigerated as in interstellar dark nebulae. The derived H_2CO production rate, 1.5×10^{28} mol s^{-1} , is consistent with the upper bound on the H_2CO production rate derived from the infrared instrument IKS flown on the VEGA space probe and with the assumed composition of the Comet Halley nucleus used in a leading theoretical model. The detection of formaldehyde in Comet Halley was successful because the VLA achieved the best sensitivity limit in the world for ground-based radio searches for formaldehyde in Comet Halley and thus it provides an impressive demonstration of the potential of ground-based arrays for future cometary observations.

THE REMARKABLE RADIO OH EMISSION FROM COMET

WILSON (19861) L.E. SNYDER

We used the Very Large Array to observe the 1667.359 MHz transition of OH in Comet Wilson on IAT days 1987 February 6 and 7, and on 1987 February 28 and March 3 (Palmer, de Pater, and Snyder (1989) Astron. J., in press). Comet Wilson was a new comet and the OH data show some remarkable differences with those for Comet Halley. In Halley, (1) we detected little OH emission from the inner coma, probably because of quenching; (2) we detected only about 1/3 of the flux detected with single dish radio telescopes, because the largest scale structure was resolved away by the VLA; and (3) the outer OH scale size was roughly spherical but appeared irregular, possibly because of excitation variations in the OH maser driven by cometosphere fluctuations. Comet Wilson was three times as far from the earth during our observations as Comet Halley was in November, 1985, but both were at about the same distance from the Sun when we observed them. Thus the gas production rates were at best comparable, at least as far as the r^2 dependence is concerned. One interesting result that we found in Comet Wilson is clear evidence for jetlike outgassing as a function of time. In comparison with Comet Halley, the radio OH emission from Comet Wilson behaved very erratically, changing rapidly in position as well as in velocity, while the emission and brightness distribution from Comet Halley displayed apparent stability. Just the opposite behavior has been observed at UV wavelengths. Another difference between the two comets is that the OH emission from Comet Halley seems confined to a region a few times 10^5 km in size, while the emission from Comet Wilson shows up in sporadic blobs, at distances as far as 10^6 km from the center, which have variable intensities and velocities. This behavior in Comet Wilson may be due to the disintegration of the outer frosting associated with new comets and possibly may be related to the fragmentation and ejection of cometesimals from the nucleus.

Using a newly introduced near infrared camera, we obtained images of the Jupiter system in the strong methane absorption band at $2.3\mu\text{m}$ and in the broadband $2.2\mu\text{m}$ atmospheric window. We were able to obtain the images of Jupiter's ring and the sheparding satellites, Adrastea and Metis, by imaging the system in the $2.3\mu\text{m}$ methane band where the disk of the planet is extremely dark. We found that the longitudes of the sheparding satellites are $\sim 20^\circ$ different than the predictions based on the ephemerides derived from the Voyager encounter observations. These new observations shall permit the knowledge of the orbit to be improved by a factor of ~ 10 , allowing a much more refined model of the interaction of the satellites with the ring. Detecting the ring in small scattering angles will also allow us to understand the sizes of the particles that comprise the ring.

A comprehensive (as of late 1988) asteroid data base has been assembled and will be published in the Asteroids II book (R.P. Binzel, T. Gehrels, and M.S. Matthews, eds.). A description of the data files, and the authors responsible for providing them, is given by Tedesco [1989, Introduction to the Asteroids II Data Base. In Asteroids II (R.P. Binzel, T. Gehrels, and M.S. Matthews, eds.), in press.]. Preliminary, machine-readable, versions were distributed, to authors of chapters who requested them, in March 1988 immediately following the Tucson Asteroid Conference. A revised machine-readable version was compiled and distributed in December 1988. Most, but not all, of these files will be printed in the Asteroids II book. Both the March and December machine-readable versions will continue to be available through the Astronomy Data Section of the National Space Science Data Center (NSSDC) at the Goddard Space Flight Center and its sister European data center, the Centre de Donnees Stellaires (CDS) at the Observatoire de Strasbourg.

TESTS OF IMPROVED CORONAGRAPHIC INSTRUMENTS ON
GROUND-BASED TELESCOPES R.J. TERRILE

Ground-based telescopes are being used to test new techniques for controlling diffracted light. These optical techniques involve the use of customized occulting focal plane and pupil plane masks in order to better concentrate and remove diffracted light in an imaging system. We have optimized the performance of a coronagraph by using an analytical model to study the effects of transparent occulting masks. We have found that by using Gaussian shaped occulting masks we can increase the effective performance of a coronagraph by about a factor of ten over classical Lyot designs. Furthermore, our high efficiency design allows imaging much closer to the bright central object because the occulting masks are transparent and do not contribute their own diffraction patterns. Currently we are testing these new coronagraph designs at various telescopes. Data acquired in this way are providing not only an improved look at astronomical objects like the circumstellar disk around Beta Pictoris, but are also providing input into the design of the Circumstellar Imaging Telescope (CIT). This telescope is intended to fly above the Earth's atmosphere in the mid 1990's and be used to directly image planets around the nearby stars.

Sufficient data are now available for the four largest asteroids (Ceres, Pallas, Vesta, and Hygiea) at several wavelengths and four smaller asteroids (Interamnia, Eunomia, Euphrosyne, and Bambergia) at one wavelength to allow spectral analyses for these eight. The spectra show that most asteroids are covered by a layer of material with the physical properties of finely-divided dust and that there is a marked change in physical properties at a depth of a few centimeters. This surface material is in layers of variable depth (typically a few centimeters) and has dielectric properties which vary somewhat from asteroid to asteroid. Disk-resolved observations of Ceres and Vesta (resolution typically 7 or so pixels along a diameter) provide no evidence of strong (30% of peak brightness or greater) microwave surface markings implying a nearly uniform spatial distribution of the microwave properties of the material.

The future availability of mm-wavelength synthesis arrays and large single antennas with good performance in the millimeter wavelength range should allow observations of the smaller asteroids which will complement both the IR and cm wavelength observations. The planned improvements to the NRAO Very Large Array will also add to the available data. Together with submillimeter wavelength, infrared and radar data, these data will provide valuable insights to the appropriate physics for a general thermophysical model for the prediction of asteroidal emission. Such a model is essential in future surface properties studies.

Results of Detailed Analysis of Asteroid Radio Continuum Spectra

Ceres: A finely-divided layer about 3 cm deep overlying a much more compact layer. The transition between the two layers is relatively sharp. The surface layer dielectric properties are best matched by a water-poor clay. The substrate dielectric properties may differ significantly.

Vesta: A finely-divided layer about 6 cm deep overlying a much more compact layer. The surface and substrate dielectric properties are best matched by basaltic dust and basalt respectively.

Pallas: A finely-divided layer at least 6 cm deep. It is not possible from the existing data to determine the dielectric properties of the substrate with any confidence. Surface dielectric properties closer to basalt than clay.

Hygiea: A finely-divided surface layer at least 8 cm deep. Surface dielectric properties closer to basalt than clay. No effects of the substrate can be found in the data.

Interamnia: A finely-divided surface layer much more than 3 cm deep.

Eunomia: A 1 cm deep surface layer which is either porous with 10% voids (most probable) or dust-like.

ASTROMETRIC OBSERVATIONS OF ASTEROIDS AND SMALL
BODIES J.G. WILLIAMS

The recovery of returning periodic comets and planet crossing asteroids is a major goal of this observational program. The Palomar 1.5 m telescope equipped with a CCD is used to hunt for the targets early in an apparition when they are still faint. During the past nine months there were recoveries of periodic comets Russell 3, Pons-Winnecke, and Clark plus a shared recovery of periodic comet Churyumov-Gerasimenko. Recoveries were also made on the earth crossing asteroids 1979 VA and 1987 SY. The near earth asteroid 1980 PA (subsequently numbered 3908) was also recovered. Recoveries are not the only goal. In all, many comets and more than a dozen planet crossing asteroids were tracked so that accurate orbits could be derived.

An improved ammonia abundance in comet Halley has been determined from NH_2 bands in optical spectra (Tegler and Wyckoff 1989). New fluorescence efficiencies have been calculated for the $(0, v'_{2,0}) \rightarrow (0,0,0)$ progression of NH_2 bands in the $\tilde{A}^2A_1 - X^2B_1$ system which lead to new NH_2 production rates for Comet Halley. The abundance ratio $\text{NH}_3/\text{H}_2\text{O} \sim 0.005 \pm 0.002$ indicates a low ammonia abundance in the nucleus, and is in good agreement with the ammonia abundance inferred from the GIOTTO ion mass spectrometer results. Ammonia abundances determined for five comets indicate a range in production rate ratios, $Q(\text{NH}_2)/Q(\text{H}_2\text{O}) \sim 10$ among the sample. Comet Halley was found to have the smallest ammonia abundance in the sample (Wyckoff, Engel, Tegler 1988). Variation of the NH_2 abundance among comets may indicate intrinsic differences in the $\text{NH}_3/\text{H}_2\text{O}$ ratio, differences in the conditions at formation, or different thermal histories of the comet nuclei after formation.

A new paradigm for the cometary nongravitational force model has been successfully employed to fit the existing astrometric data for several periodic comets. With the introduction of the new model, the water vaporization curve used to model the rocket-like thrusting that occurs on a comet's icy nucleus, is allowed to peak on either side of perihelion. Thus, the resulting nongravitational force that affects a comet's motion, is due to an asymmetric radial force, rather than the symmetric transverse effect that the old model requires. Orbital solutions for several comets suggest that the optimum location of the water vaporization peak, required for the nongravitational forces, aligns with the location of the visual light curve peak. For example, comet d'Arrest has a light curve that peaks approximately 40 days after perihelion suggesting that the comet's outgassing also reaches a maximum at that time. Orbits using the new nongravitational force model achieve a minimum RMS observation residual (best fit) when the water vaporization curve for comet d'Arrest is displaced 40 days after perihelion. The results from similar solutions for comets Kopff, Giacobini-Zinner and Halley will require revisions in thinking about the spin pole histories of these objects.



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